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THE STRATIGRAPHY AND SEDIMENTATION OF THE FOREST MARBLE
FORMATION (BATHONIAN, MIDDLE JURASSIC) IN THE AREA BETWEEN
BRADFORD-ON-AVON AND THE DORSET COAST (SOUTHERN ENGLAND)

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ABSTRACT

This study is an integrated facies analysis of the Forest Marble Formation (Upper Bathonian Middle Jurassic) in the area between Bradford-on-Avon and the Dorset coast (Southern England).

The Forest Marble is a mixed carbonate/clastic shallow marine sequence between about 20m and 30m thick. It is characterised by very rapid vertical and lateral facies changes and so has not been formally subdivided into members. The stratigraphic setting and chronostratigraphy of the Formation are described in Chapter One.

The Formation has been divided into four Facies Associations, described in Chapters 2, 3, 4 and 5. Association A (Marl-dominated Facies Association) is considered to have been deposited around or slightly above normal wave base. Association B (Hardgrounds and Firmgrounds Facies Association) is interpreted as representing periods of depositional hiatus during which substrates hardened to varying degrees allowing the development of benthic communities dominated by epifauna. Association C (Calcirudites Facies Association) is composed largely of coarse shell debris interpreted as representing a series of shallow marine shoals, shell sheets, sandwaves and channels formed in conditions influenced by both waves and tides. Association D (Heterolithic Facies Association) is composed of mixed sand and marl lithologies with rare developments of faunas and is thought to have deposited in very shallow, possibly somewhat restricted, marine conditions.

Chapter Six is an interpretation of the Formation as a whole based largely on the interpretation and spatial distribution of the Facies Associations. It is considered to represent a shallowing upwards regressive sequence deposited between the London Landmass and the Channel Basin.

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Enclosure 1. "Aide-memoire" listing facies by number with summary description where appropriate.

<u>Facies number</u>	<u>Facies name</u>	<u>Summary description</u>
1	Calcareous marl	Marl with silt wisps
2	Silt streaked marl	
3	Sand streaked marl	Marl with sand streaks and thin rippled calcareous sandstones
4	Marly sandstones and sands	Fine sands with marly matrix
5	Graded sandstones and bioclastic limestones	'Storm deposits'
6	Hardgrounds	Developed in carbonates - usually with associated bradfordian fauna
7	Firmgrounds	Consolidated sediments with open burrows but not encrusted or bored -associated with bradfordian faunas
8	Flat bedded and cross bedded sheets and lenses of calcirudite	Shell detrital calcirudite normally incorporated in shoal sequences
9	Channel fill facies	Calcirudite channel fills
10	Ripple cross-laminated calcarenite	
11	Imbricated calcirudite	Obliquely imbricated shell debris-produced by unidirectional currents
12	High angle cross-bedded calcirudite	Cross bedding with foreset angle greater than 5°.
13	Giant scale cross-bedded calcirudite	Sets up to 8m high interpreted as sandwaves
14	Micrites	Cream coloured, burrowed biomicrites
15	Lenticular bedded sands	
16	Ripple cross-laminated sands	
17	Structureless sandstone	
18	Mud flake conglomerates	Channelised sands with marl intraclasts
19	Low angle cross-laminated sands	Sands with cross bedding lamination of less than 5°, interpreted as shoreface deposits

PREFACE. FACIES AND FACIES ASSOCIATIONS

A facies can be defined as a body of rock with specified characteristics. As far as sedimentary rocks are concerned, facies are usually defined on the basis of bedding, composition, texture, fossils, sedimentary structures and colour. Ideally this should lead to the definition of facies as distinctive rocks that form under certain conditions of sedimentation, reflecting a particular process or environment (Reading, 1978, p.4).

The principle behind facies analysis is that these defined rock types can be used to interpret processes and/or environments and hopefully may be combined with each other to provide an interpretation of the conditions of deposition of rock sequences.

The interpretation of rock sequences can often be helped by grouping the facies into associations; groups of facies that occur together in the field and which, ideally, are considered to be genetically or environmentally related.

The grouping of facies into associations allows an individual facies to be interpreted in relation to neighbouring facies; either those laterally equivalent to it or those that immediately underlie or overlie it.

An individual facies may occur in more than one facies association, merely reflecting the principle that similar processes or environments may occur sporadically within sequences that are considered to have originated in different environments or by different processes.

The power of the technique is that it should allow facies that cannot easily be assigned to a particular environment of deposition, or even to a specific process of origin when considered in isolation, to be interpreted in relationship to surrounding facies. Thus

facies which are not environment-specific and which may be only interpretable in terms of broad processes may be assigned to more specific processes when considered in context. For example, sharp-based sandstones which fine upwards and contain a Bouma sequence of sedimentary structures are normally interpreted as the products of decelerating flows. Interpretation of neighbouring facies may enable them to be placed in, for example, an alluvial or deep-sea context perhaps suggesting an interpretation as crevasse splay or sheet flood deposits in the first case or as turbidites in the second.

However, facies should not always be interpreted in relation to their neighbours. Great attention must be paid to the nature of their contacts. This was stressed by Walther (1894) in his law of facies, which applies only to successions without major breaks. Discontinuity surfaces should be recognised as being possibly the only representatives of environments which occurred during the deposition of a sedimentary sequence but which are not recorded within the sequence.

In this thesis the sediments of the Forest Marble Formation have been divided into four facies associations known simply as Associations A, B, C and D. These include several facies which are poorly understood in terms of process and/or environment, but all facies are considered to be compatible with the environmental interpretations of the facies associations. Consequently in the final chapter of the thesis, heavy emphasis has been placed on the significance of the vertical and lateral distribution of the facies associations in the environmental interpretation of the Formation as a whole.

The layout of the thesis is such that the facies in each Association are described and interpreted and are followed by a brief interpretation

and discussion of each Association. Where a facies occurs in more than one association it is only fully described at its first occurrence. In the final chapter the field relationships of the associations in the study area are described and an interpretation of the Formation as a whole is attempted.

Introduction

The aim of this study was to make an integrated facies analysis of the Forest Marble Formation (Upper Bathonian Middle Jurassic) in the area between Bradford-on-Avon and the Dorset coast. This was undertaken to more fully understand the stratigraphy, palaeoenvironments and palaeoecology of the Formation.

The main fields of study were the sedimentology, palaeontology and ichnology.

The Forest Marble Formation in the study area is characterised by very rapid vertical and lateral facies changes which make it unsuitable for subdivision into formal lithostratigraphic members. This point is emphasised by the considerable controversy over the subdivision of the formation as a whole during the last century. This problem has been stabilised with the establishment of the Forest Marble as a Formation by Palmer (1974). Details of the historical background to the stratigraphy are given on p. 18.

Biostratigraphic subdivision of the Formation has also proved very difficult owing to the extreme rarity of ammonites. As biostratigraphic and lithostratigraphic subdivisions are rather uncertain, the Formation has here been divided into a number of facies. These are defined on a combination of sedimentological, palaeontological and other data. As far as possible, facies definitions are confined to criteria recognisable in the field, but this is not always the case.

The facies have been grouped into associations which are groups of facies which are, in most cases, thought to be genetically closely related. In some cases, in which the genesis of a particular facies is not well understood, some facies have been included together in

associations of sediments with which they are commonly associated in the field.

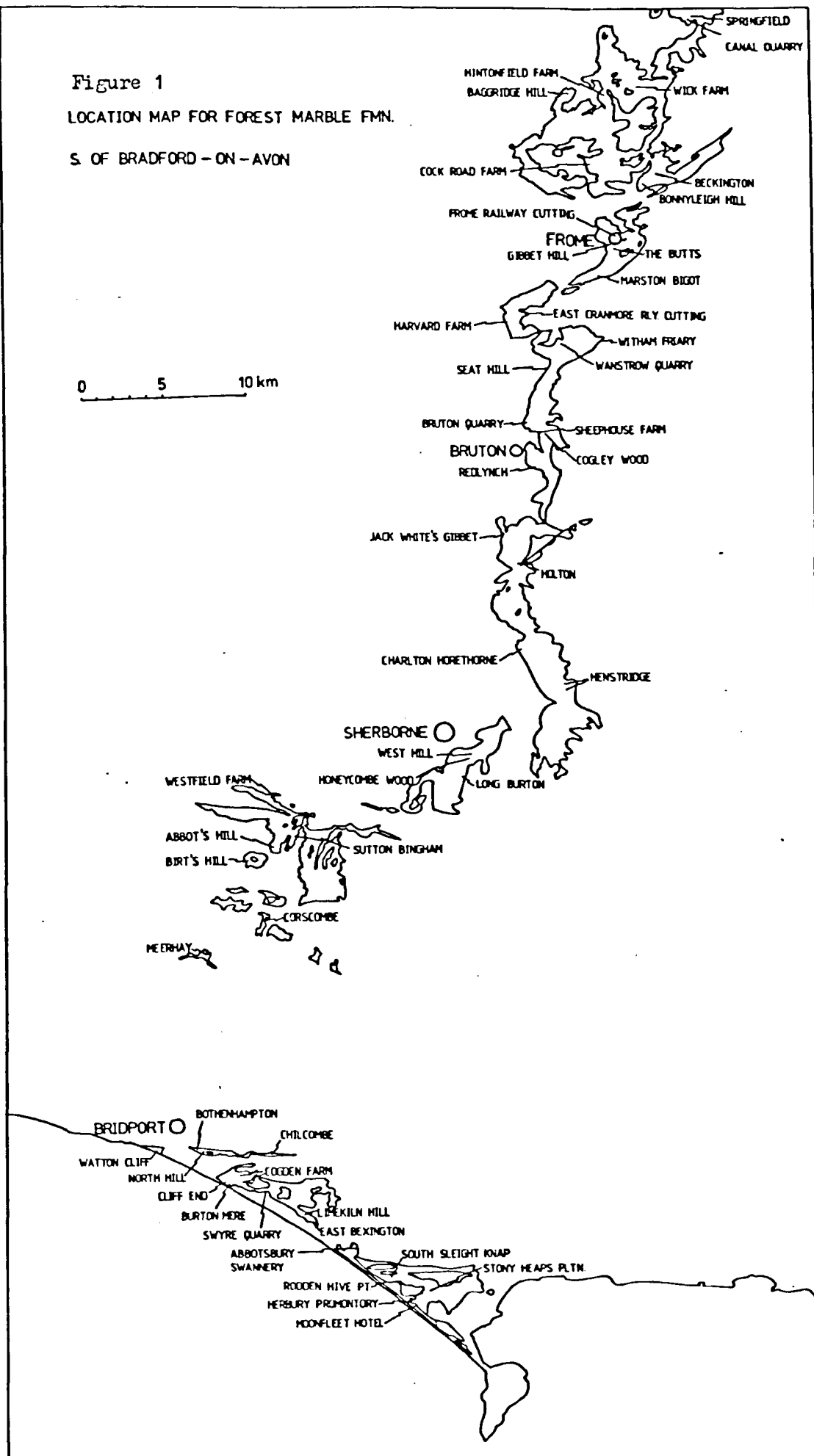
The facies and facies associations are described and interpreted and their field relationships described. An attempt is then made to draw together all these results and provide a generalised interpretation of the succession.

All localities between Bradford-on-Avon and the Dorset coast were visited, but many are only small or partially infilled quarries. Logs and descriptions of the important sections are recorded in the text and the locations of sections mentioned in the text are shown in figure 1.

The type section of the Forest Marble Formation is at Shipton Cement Works (SP 4717), Oxfordshire. This was proposed "somewhat reluctantly" by Palmer (1974). Although the Formation at this locality is not quite typical of the sequence in Dorset and Somerset, as it lacks a well developed in situ fauna, no section can be regarded as typical of the Forest Marble throughout its outcrop, and I firmly support his choice since it is in the region where the Formation was first named.

Figure 1
 LOCATION MAP FOR FOREST MARBLE FMN.
 S. OF BRADFORD - ON - AVON

0 5 10 km



Bathonian Palaeogeography in Southern England

During the Bathonian, sedimentation in southern England took place in a large epeiric sea covering the area known as the Anglo-Paris Basin. This was roughly centred on Paris and its limits are defined by three, possibly four, land areas. Well documented land areas then existed in the Massif Armoricaïn and Massif Central, both of which probably formed large islands (Arkell, 1956 p.39).

To the north of the basin was a more continuous land area formed by the Vosges, Ardennes and the so-called London Landmass - a continuation of the Vosges-Ardennes landmass northward into southern England. The London Landmass has been proved in several boreholes, e.g. Richmond (Martin, 1967). Its inferred shape is shown in figure 2.

The fourth landmass may have existed not far to the west of the present-day Bathonian outcrop in southwest England. Martin's isopachytes suggested that the Bathonian outcrop thins considerably in the area west of Frome. This supported the idea that land lay very close to the Mendip area. However, it is certain that this apparent thinning is based on a misleading outcrop measurement of Woodward (1894), who failed to recognise a fault in the section at Bonnyleigh Hill near Frome. In fact the Bathonian is probably still between 75 and 90m thick in the area around Frome (Ponsford, 1969). If Martin's isopachyte map is modified to take account of this, e.g. as by Green and Donovan (1969), a westerly thinning of the Bathonian is still observed, though it is not so marked in the Mendip area, and nowhere suggests that land was present in the Mendips at this time. The presence of land in this area during Fuller's Earth times has also been refuted (Sylvester-Bradley and Hodson, 1957).

The great thicknesses of Bathonian sediment shown by Martin in West Dorset are similarly not supported by outcrop measurements

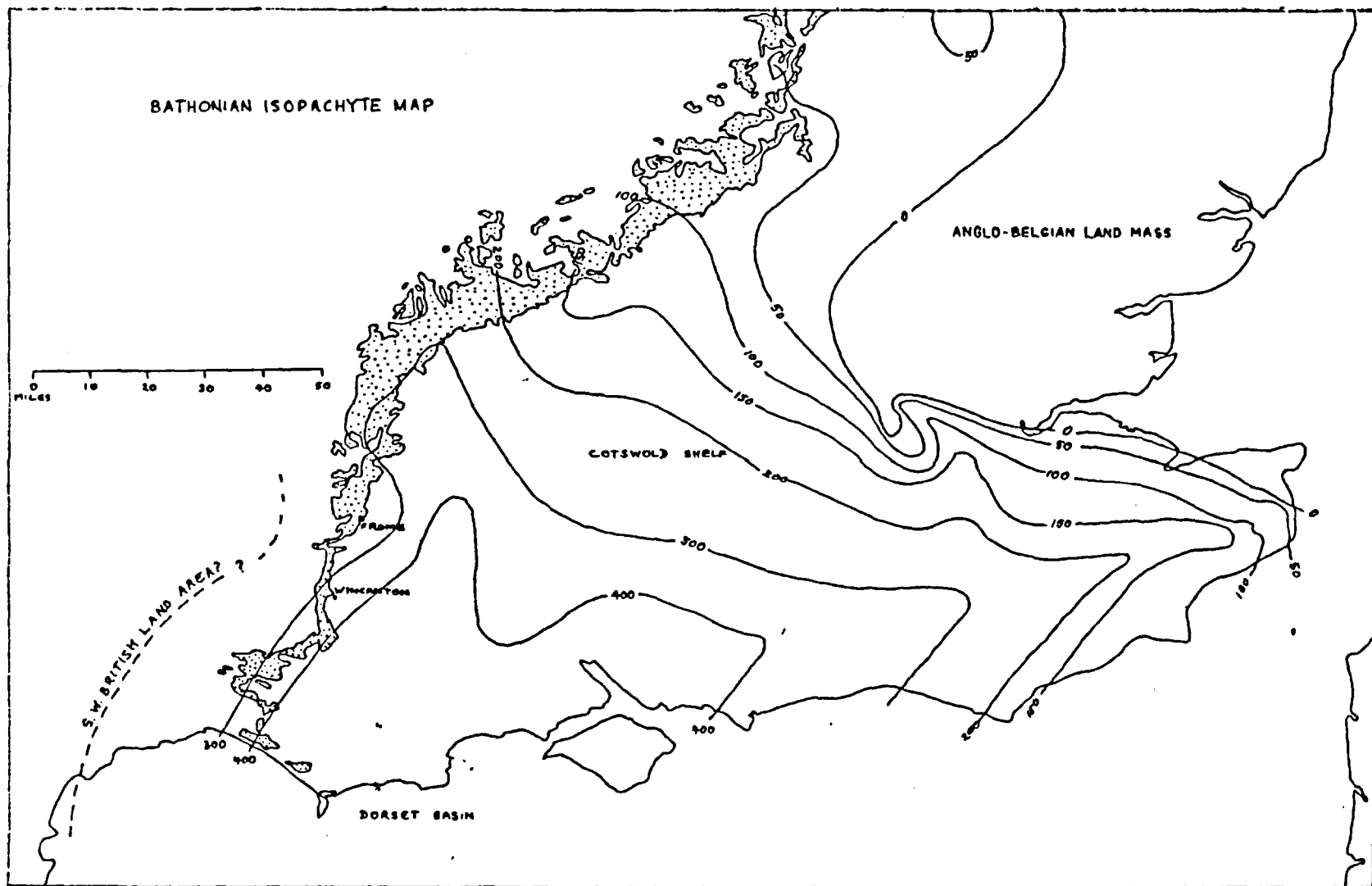


Figure 2. Bathonian isopach map adapted from Martin (1976) and Green and Donovan (1969). Thicknesses in feet.

(Ponsford, 1969). It has been suggested that the Radipole borehole at least, is affected by reverse faulting (House, 1961) and this also probably occurs in the Seabarn Farm borehole, near Langton Herring. However, the great thickening is recorded in several other boreholes, many of which are not cored, e.g. Lulworth Banks No.1.

Buckman (1922) estimated the thickness of the Fuller's Earth at Watton Cliff as 108m, which, adding the thickness of the Forest Marble, suggests a Bathonian thickness of some 144m. This is considerably less than the 181m estimated by Martin (1967).

As there is such a contrast between the apparently unfaulted outcrop sections, such as that at North Hill near West Bay (SY 485906), and the borehole measurements, no thicknesses are given in the West Dorset area on the isopachyte map shown as figure 2. This map is modified from Martin (1967) and Green and Donovan (1969).

The heavy minerals of the Forest Marble show no evidence of Dartmoor Granite detritus such as the clearly zoned zircons considered by Groves (1931, p.63) to be characteristic. He points out that there is no evidence whatever of direct derivation of detritus from Dartmoor in the Jurassic rocks of Dorset, nor inland as far as Oxford (Groves, 1931, pp.86-87). Thus if a south-west land area was present at this time, it is very unlikely to have incorporated Dartmoor.

Bathonian sediments exposed in southern Britain are principally marine and include both carbonate and detrital components. Nearshore shallow-water facies are developed west and north-west of the London Landmass and these, in general, pass westwards into facies of a more distal character.

To the north, extensive deltaic facies of Bathonian age are developed in Yorkshire and parts of the North Sea. In the Bristol

Channel area there is no evidence of limestone development and the majority of the sequence is composed of terrigenous marls, though many of these rocks are not of proven Bathonian age (Evans and Thompson, 1979). The middle Bathonian palaeogeography of north-west Europe, incorporating data from North Sea cores, is discussed by Callomon (1979) who presents a palaeogeographic reconstruction.

Introduction to lithostratigraphy of the Formation in the study area

In the area south of Bradford-on-Avon, the Forest Marble falls naturally into three lithological units of approximately equal thickness, as recognised by Arkell (1947). These correspond approximately to the three main lithofacies associations recognised in the Formation, i.e. facies associations A, C and D. The lower division (which approximately corresponds to association A) is dominated by argillaceous sediments, chiefly marls, sand-streaked marls and silt-streaked marls and may contain subsidiary developments of coarse, shell-detrital sparites, calcarenites and sandstones. Where biosparites occur, they are usually in units less than 30cm thick. Biosparites are more common in the lower part of the succession north of Wincanton. At Watton Cliff on the Dorset coast, only one thin biosparite horizon is present below the main biosparite unit, whereas at Redlynch (ST 697332) for example, thin calcirudite horizons are common from 20cm above the base of the Boueti Bed to at least 3m above its base.

Autochthonous macrofaunas are sparse in the lower Forest Marble and are normally confined to thin and patchy developments of benthonic faunas.

The central unit of the Formation (approximately equivalent to association C) in the area south of Bradford-on-Avon is dominated by carbonate sediments. It is composed largely of coarse, shell-fragmental, intraclastic, oolitic sparites. These occur grouped in cosets 20cm to 8m thick and are associated with less well developed micrites and marls. Thick developments of calcirudites occur in all sections studied. They form a prominent scarp along the Forest Marble outcrop, particularly well developed between Marston Bigot and Frome and also on the Dorset coast. However, they are not considered to form a continuous sheet. Rather, they are a set of strongly lensoid over-

lapping shell accumulations including those of both positive (shoal-like) and negative (channel-like) relief. The faunas are largely allochthonous and are dominated by epifaunal bivalves with subsidiary echinoderms, gastropods, bryozoans, brachiopods, infaunal bivalves, ostracods, forams and vertebrates. There is a very notable dearth of cephalopods.

The micrites are a cream colour and are generally highly burrowed. They contain an infauna dominated by shallow burrowing pelecypods and also allochthonous shell material similar to that found in the shell-detrital calcirudites.

Above the central limestone unit there is normally a facies change to linsen-bedded, thin, very fine-grained sandstones and calcareous marls. Towards the base of this unit (approximately equivalent to association D) , interbedded thin calcirudites may occur. The sands contain well preserved trace fossil assemblages and have faunas dominated by ostracods. Large quantities of finely divided lignite detritus may also be present.

Locally, thicker sand bodies occur above the central limestone division of Arkell (1947). These increase in number and thickness northwards, the thickest being in the region of Hinton Charterhouse, whence they derive the name Hinton Sands. These sand bodies are up to 10m. thick and are lensoid in shape (Periam, 1956). They contain rare bivalves and a few trace fossils. Lithologically the sands are very fine grained and contain marl intraclasts, drapes and partings. They are cemented to varying degrees by carbonates and show some diagenetic concretions which often obliterate sedimentary structures.

Very near to the top of the Formation, rare oyster lumachelles up to 2m thick occur. These contain a diverse epifaunal and encrusting fauna and may have a pelleted marl matrix. Only three have been

recorded in the study area; at Witham Friary (ST 74454170), West Hill, Sherborne (ST 642147) and near North Coker (ST 534128).

In this thesis, Arkell's (1947) three-fold subdivision of the Formation as applied to the area in general is considered useful. His three main lithological subdivisions of the Forest Marble are referred to as the lower, middle and upper Forest Marble. As is clear from the brief description of the lithologies given above, this is a loose frame of reference as rapid lateral facies change and inter bedding of the main lithologies is the rule rather than the exception. Therefore these useful units are not sufficiently well defined to allow the division of the Formation into formal lithostratigraphic members. Also it is a basic tenet of facies analysis that facies should be independent of stratigraphy and, in some sections at least, Arkell's subdivisions do not apply to the sediments of the study area.

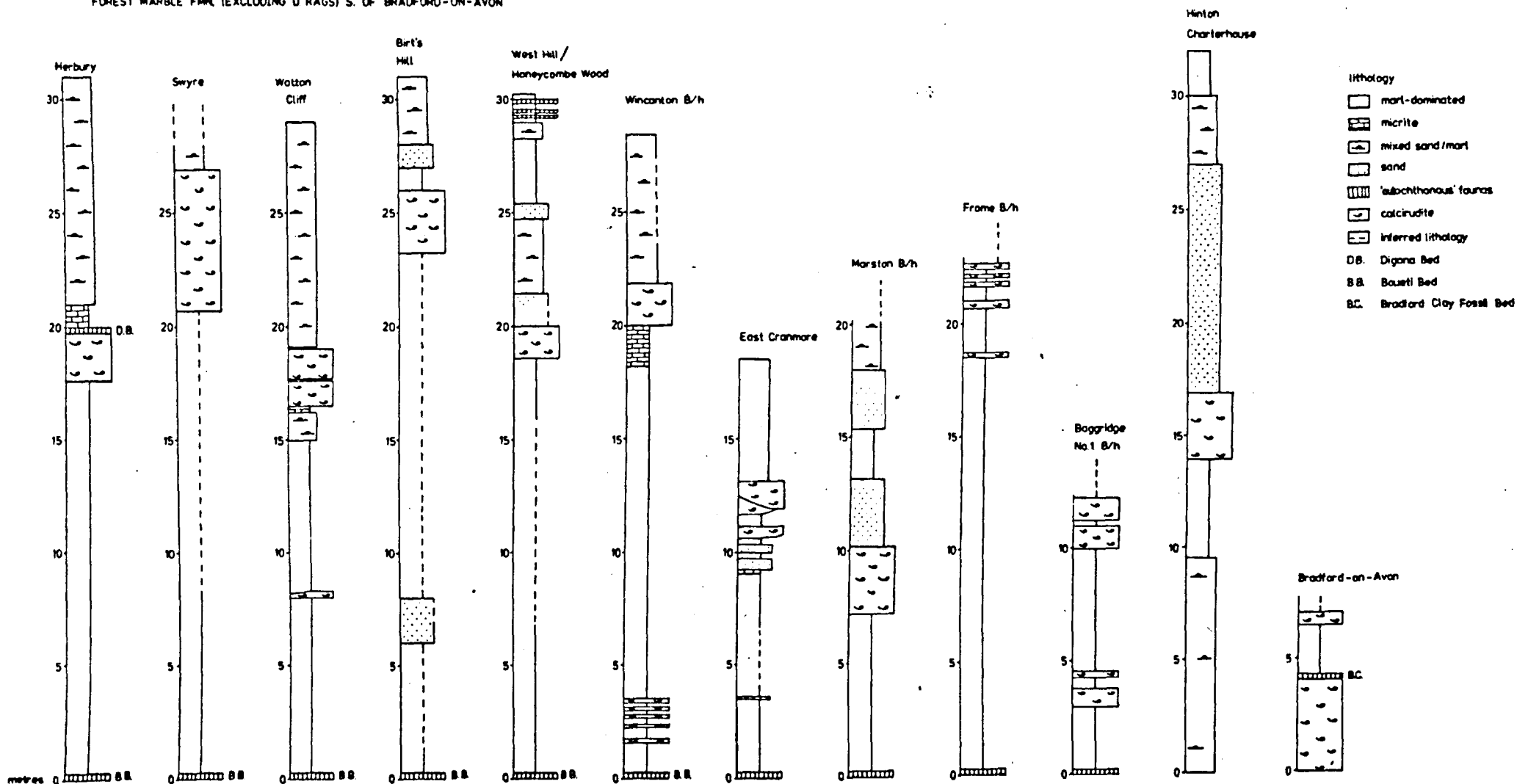
This becomes increasingly clear to the north of the study area, where the Forest Marble changes from dominantly marls in the south of the Malmesbury area to dominantly bioclastic limestones in the north of that area. It appears possible that the basal bioclastic developments of the northern half of the study area may become better developed in the Malmesbury district, but the poor definition of the base of the Formation here prevents confirmation of this.

The thickness of the Formation in the study area is not always easy to estimate as complete, well exposed sections are rare. It varies between about 39.5 - 42.7m at Herbury promontory on the Dorset coast (Arkell, 1947, p.18) and approximately 22.5m in the Wincanton area.

Thickness variation and gross lithology are shown in the sections below (fig. 3).

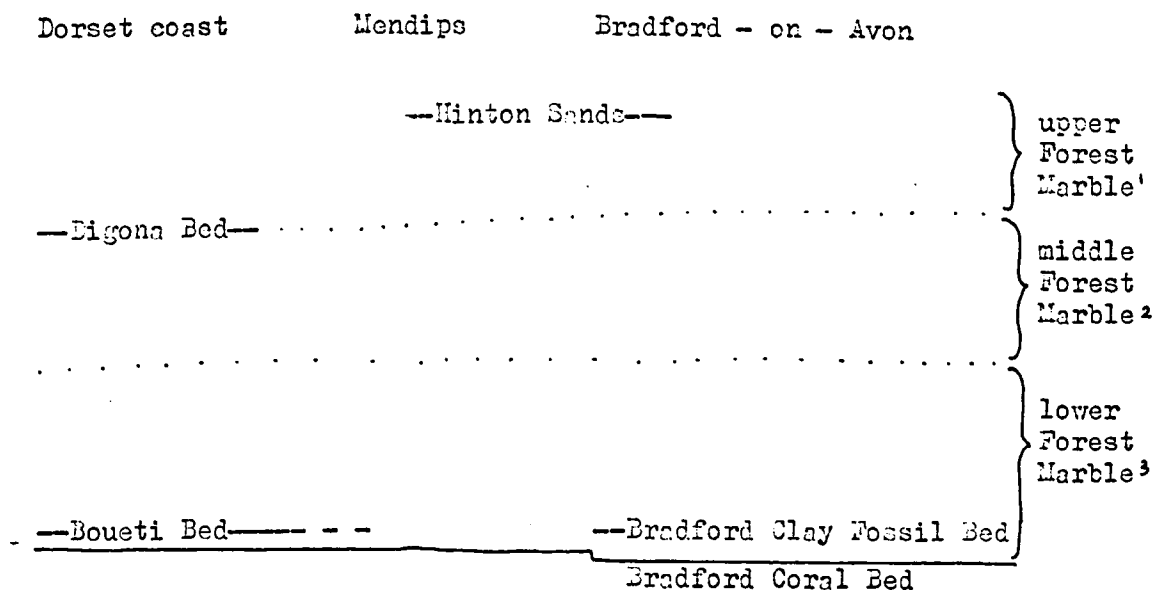
Figure 3.

THICKNESS AND GROSS LITHOLOGY IN SELECTED SECTIONS THROUGH THE
FOREST MARBLE F.M. (EXCLUDING U RAGS) S. OF BRADFORD-ON-AVON



Stratigraphic usage in this thesis follows Green & Donovan (1969) in the area north of the Mendips and Woodward (1894) and subsequent authors in the area to the south of the Mendips. Stratigraphic terms such as the Boueti Bed, Bradford Clay Fossil Bed (Arkell, 1933), Digona Bed (Torrens, 1963) and Hinton Sands (Periam, 1956) are retained, as is Arkell's (1947) subdivision of the formation into lower, middle and upper Forest Marble, but no new lithostratigraphic units are proposed (see discussion p. 1). In practice the stratigraphic usage in the area south of the Mendips has not been disputed this century, whereas north of the Mendips it remains a matter of considerable controversy (see pp. 7 - 21, fig. 6).

The stratigraphic usage is shown below and may be compared with that of earlier authors shown in fig. 6.



¹ predominantly mixed sand / marl lithologies

² predominantly calcirudite lithology

³ predominantly marl - dominated lithology

Limits of the Formation in the study area

In the study area, the Forest Marble can easily be distinguished from the overlying Cornbrash on both lithological and faunal criteria. The lithology of the Lower Cornbrash is typically a sandy bioclastic rubbly limestone, though occasionally the lowest beds are of calcareous marl. In the latter case the junction with the Forest Marble Formation cannot be defined lithologically with absolute precision. Only one such section has been recorded; at Meerhay (ST 484026). It is characterised by the presence of faunas associated with the Lower Cornbrash, including Obovothyris sp. (juv.) and Pholadomya deltoidea. In all other sections examined, the base of the Cornbrash was easily defined and a transition over a few centimetres from interbedded thin sandstones and marls of the upper Forest Marble Formation to rubbly, sandy Cornbrash limestone is characteristic of the junction. Details of the sections in the lower Cornbrash Formation of the area were given by Douglas and Arkell (1928).

The base of the Formation is not always so easy to define. In the study area the Forest Marble (sensu Green and Donovan, 1969) overlies either the Upper Rags or the upper Fuller's Earth Formation.

South of the Mendip Hills, the base of the Formation is easily defined by the base of the Boueti Bed (Arkell, 1933). This is an extremely fossiliferous, grey, partially pelleted, marl up to 50cm thick. Whilst it is identified by the presence of the index brachiopod Goniorhynchia boueti (Davidson), G. boueti shells are present in sufficiently large numbers to form an integral part of the lithology, so the base of the Formation is not defined by a palaeontological criterion alone, but by the base of a bed of distinctive lithology. The Boueti Bed can be traced with confidence at outcrop as far north as the southern slopes of the Mendip Hills, at Seat Hill, Batcombe

(ST 707394), and has been reported as far north as Harvard Farm, West Cranmore (ST 67954180).

G. boueti is not confined to the Boueti Bed in England as thought previously, but occurs rarely within the body of the Forest Marble Formation. Two disarticulated valves have been found in the central shell-detrital limestones approximately 15m above the Boueti Bed at Watton Cliff, West Bay. However, these are obviously allochthonous and merely reinforce the notion that the base of the Forest Marble Formation should not be defined on palaeontological grounds.

The fauna of the Boueti Bed is well known (Richardson, 1909; Fowler, 1957; Torrens, 1969). It is dominated by bivalves and brachiopods and a diverse encrusting fauna of serpulids, ectoprocts and rare algae. The fauna as a whole is of a type which has become known as a bradfordian¹ or Bradford Clay fauna, after the fauna in the famous Bradford Clay Fossil Bed at Bradford-on-Avon (Cunnington, 1860; Periam, 1956; Palmer, 1974). These faunas are discussed more fully below in Chapter 3.

The Boueti Bed has not been recognised on or over the Mendips as the index fossil has not been recorded further north than Harwood Farm, West Cranmore (ST 67954180) (Green and Donovan, 1969). In its absence the base of the Formation is extremely hard to define. There is little of no lithological difference between the calcareous marls of the Upper Fuller's Earth and Lower Forest Marble in the critical part of the sequence, and consequently other criteria must be used. The section at a railway cutting leading to Merehead Quarry, East Cranmore (ST 695434) exemplifies this problem, see fig.14. Here G. boueti is not present, but a band of bored, encrusted and pyritised calcareous concretions occurs about 12m below the middle Forest Marble bioclastic limestones. The exact level at which this horizon occurs is uncertain,

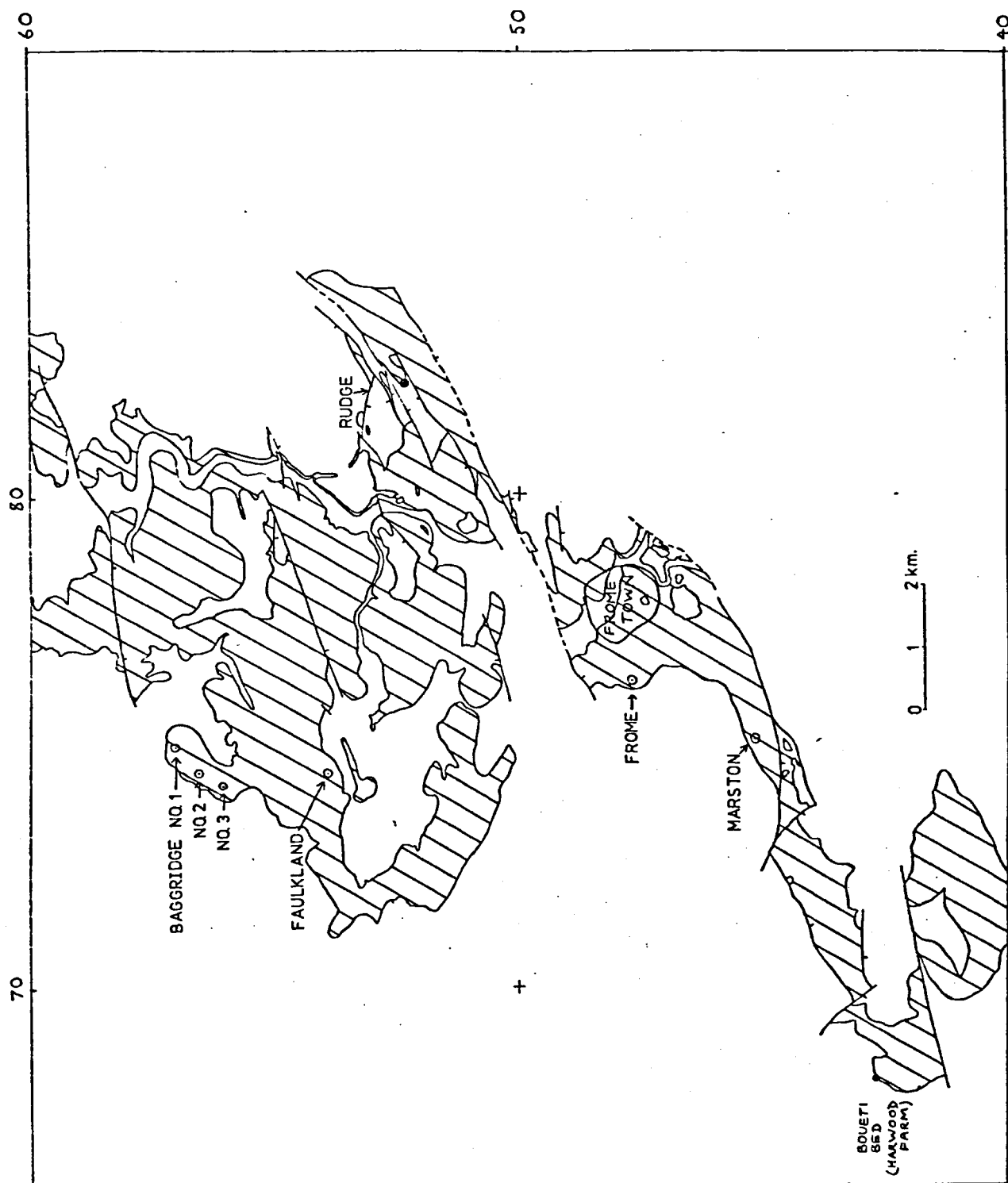
¹The term bradfordian is used in order to distinguish the description of the fauna from the stratigraphic term Bradfordian, see pp.18 - 19 .

as the section contains a large number of minor normal faults. However, it is at approximately the same stratigraphic level relative to the bioclastic limestones as the northernmost Boueti Bed localities and may pass laterally into it, as the associated bradfordian fauna is very similar. However, this is very difficult to prove in the absence of the diagnostic brachiopod as bradfordian faunas are widespread both within and below the Formation. The picture is further complicated as the central Forest Marble limestones occur at different levels within the Formation, so no fixed marker horizon is available from which to determine whether a particular bradfordian fauna is laterally equivalent to the Boueti Bed, even in borehole logs. Exposure over the southern Mendips is very poor and over much of the area the base of the Forest Marble appears to be faulted out and attempts to trace the Boueti Bed northwards have been unsuccessful, though occasional developments of bradfordian faunas may be encountered in stream sections, e.g. at the Butts, Frome (ST 765472).

Borehole records at Marston (Little Sharpshaw Farm) and Frome (Gibbet Hill) show a bradfordian fauna occurring at depths of 20.9m. and 18.1m. beneath soil surface respectively. This is at approximately the same stratigraphic level relative to the central limestones around Bruton. This marker horizon is taken as the base of the Forest Marble Formation (as indicated on the borehole logs of R.G. Wyatt) simply because it has a similar fauna and occurs at a similar level as the Boueti Bed. It is not the lowest bradfordian fauna in these boreholes nor is it mappable at outcrop. The location of boreholes in the Bath-Frome area is shown in fig. 4.

North of the Mendips, from Baggridge Hill (ST 745568) northwards, the Forest Marble Formation (sensu Green and Donovan, 1969) overlies the Upper Rags. The Upper Rags is composed principally of oolitic

Figure 4.



Location of cored boreholes penetrating the Forest Marble Formation in the Bath - Frome area. Outcrop of the Forest Marble shaded.

micritic bioclastic limestones, but northwards, from just north of Hinton Charterhouse, their uppermost division is the Bradford Coral Bed. This is a single, very hard, crystalline, coralline limestone 1.3 - 2.0m. thick (Green and Donovan, 1969).

At Baggridge Hill, the base of the Formation (sensu Green and Donovan, 1969) is taken at a hardground on top of the Upper Rags clearly shown in the Baggridge No.3 borehole. Here the underlying lithology is a creamy-white, fine-grained, shell-fragmental oolite and cream shell-detrital calcarenite.

In the extreme north of the area, at Bradford-on-Avon, approximately 3.5m. above the Coral Bed, is a well known, though poorly exposed, hardground with an associated fauna which overlies cross-bedded, shell-detrital, oolitic limestones identical in the field appearance to Forest Marble limestones higher in the succession. This fauna is at the base of the Bradford Clay and is the Bradford Clay Fossil Bed (see below). The Bradford Clay is a very early stratigraphic term used originally in the Bath area by J. de C. Sowerby (1823) and has only a local significance. It refers to the clays between the Fossil Bed and the central shell-detrital limestones of the Forest Marble Formation.

Stratigraphic setting of the Forest Marble Formation

The definition of the stratigraphical and lithological limits of the Forest Marble Formation throughout the outcrop has been a matter of contention since at least the early part of this century and is still a very difficult problem. As the term "Formation" is a litho-stratigraphic one (Holland et al., 1978) the Formation should be defined as far as possible on lithological grounds. However, as so many of the facies in the Bathonian of southern Britain and the Midlands vary only subtly in lithology and as the beds show frequent lateral facies changes, many Formations must be defined on a combination of faunal and lithological criteria.

The Forest Marble Formation, which is middle Upper Bathonian in age (Torrens, 1980), forms part of the Great Oolite Group (McKerrow and Kennedy, 1973; Palmer, 1974). This group constitutes an extremely complex mosaic of lithosomes, many of which are not closely defined owing to poor exposure, extremely variable lithology and lack of certainty about their exact stratigraphic relationships. The group is at its simplest in West Dorset, where the succession (fig.5) is:

Part of Cornbrash	2.2m
Forest Marble Formation	28.0m
Fuller's Earth Formation	97.5m

This continues northwards with little change until north of the Mendip Hills. In the area around Hinton Charterhouse and Bradford-on-Avon, bioclastic and oolitic shell-fragmental limestones appear between the Fuller's Earth and Forest Marble Formations. These are subdivided as below (Green and Donovan, 1969):

Cornbrash
Forest Marble Formation
Upper Rags

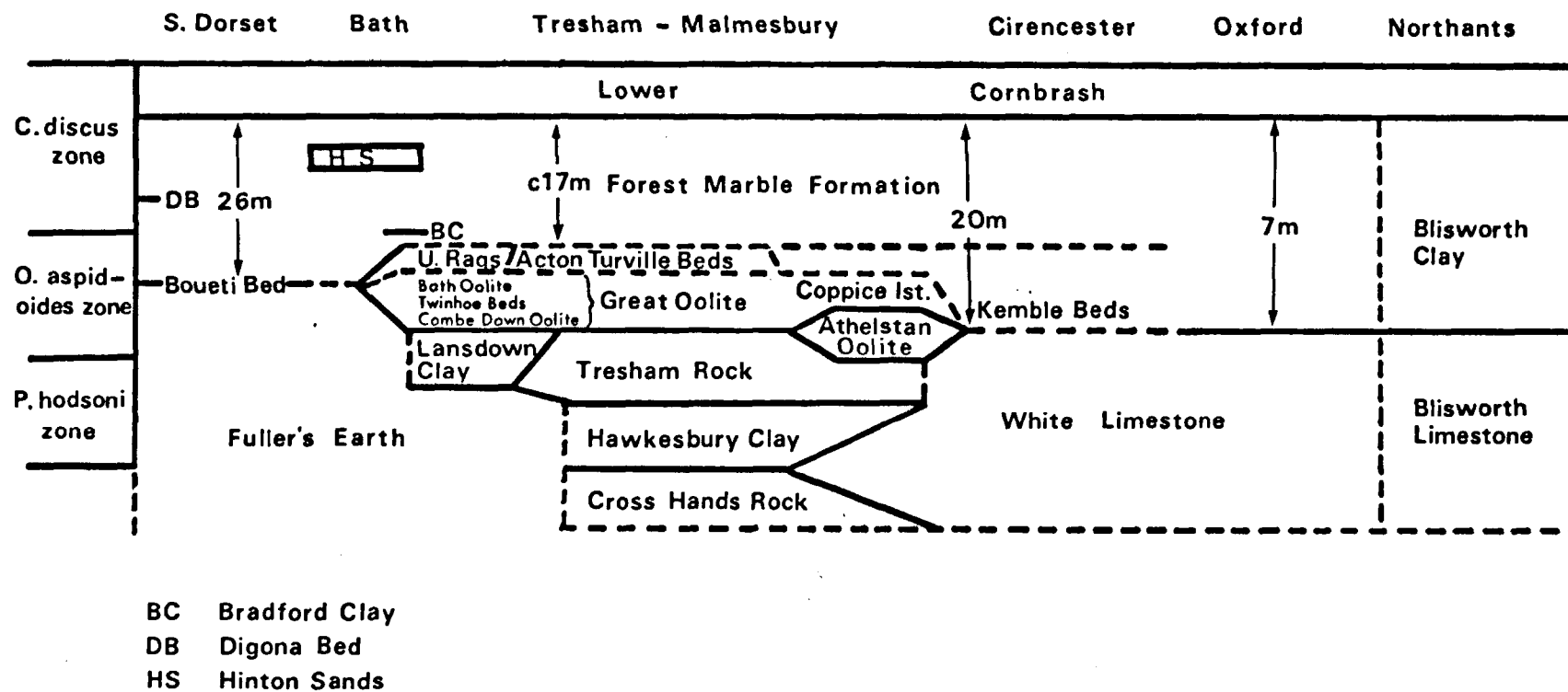


Fig. 5 Chronostratigraphic correlation of lithostratigraphic units in the Upper Bathonian. Adapted from Torrens *in* Cope *et al.* (1980).

Bath Oolite

Twinhoe Beds

Combe Down Oolite

Fuller's Earth Formation

These four limestone units thicken rapidly to the north and west reaching a total thickness of about 30 metres near Bath, which lies only 8 km. from the point of their first appearance.

Green and Donovan (1969), in their classic study of the Great Oolite of the Bath area, group together the beds above the Fuller's Earth Formation and below the Forest Marble Formation as a "major stratigraphical unit"; the Great Oolite. The exact status of the components of this unit is not made clear, nor is it obvious whether the unit as a whole is intended as the basis for a Group or a Formation in the sense of Holland et al. (1978).

Thus, in southern Britain, it is extremely important to recognise the difference between the Great Oolite (limestones) of Green and Donovan (1969) and the Great Oolite Group of McKerrow and Kennedy (1973). In this thesis the term "Great Oolite" is, as far as possible, avoided. Where it is used, the distinction between the two usages made above is observed.

Recently, borehole evidence has been used to change the interpretation of the Bathonian stratigraphy of the Bath area (Penn and Wyatt, 1979). In their account, the Upper Rags is regarded as the basal member of the overlying Forest Marble Formation. It is also suggested that the Great Oolite (limestones) pass southwards into a predominantly mudstone sequence distinct from the Fuller's Earth Formation and the Forest Marble Formation (sensu Penn and Wyatt, 1979 p.38, fig.10). This they call the Frome Clay.

To the northwest, in the Malmesbury district, the base of the

Formation has also been defined at this lower level (in a lithological sense, at least). Beds believed to be "equivalent" to the Upper Rags, (i.e. beds that are thought to pass laterally into the Upper Rags), are included within the Forest Marble Formation (Cave, 1978). The generalised succession in this area is:

N. Lower Cornbrash S.

Forest Marble (including Acton Turville Beds)

Coppice Limestone Great Oolite bioclastic limestones

Athelstan Oolite Lansdown Clay

Tresham Rock Tresham Rock

Hawkesbury Clay Hawkesbury Clay

Cross Hands Rock Cross Hands Rock

Lower Fuller's Earth Clay Lower Fuller's Earth Clay

The Acton Turville Beds are described by Buckman (1924), Arkell (1933) and Cave (1978).

The Coppice Limestone is not always present beneath the Forest Marble and a hardground may be developed between it and the Athelstan Oolite. The Coppice Limestone is a thin, hard, porcellanous limestone. It is noticeable that the lower units, including those from the Athelstan Oolite to the Lower Fuller's Earth Clay, contain more limestones and particularly oolites than their correlatives in the south-western area. These units are described by Cave (1978).

The Great Oolite bioclastic limestones in the south of the Malmesbury area may pass laterally into the Coppice Limestone (Cave, 1978).

Whilst it may be true that the Acton Turville Beds pass laterally into beds which are indistinguishable lithologically from those of the Forest Marble Formation and which are considered also to pass laterally into the Upper Rags of the Bath area, they are not here considered to be part of the Forest Marble Formation, as they themselves are distinguishable lithologically from the Forest Marble. Whilst this is easily reconciled in terms of current lithostratigraphic practice,

it is not so easily justified in mapping terms (Cave, 1978; Penn and Wyatt, 1979).

The thickness of the Forest Marble Formation as defined by Cave (1978), i.e. including the Acton Turville Beds, is approximately 28m. in the south of the Malmesbury area (Cave, 1978, p.150).

To the north of the Malmesbury area, in the Oxford district, the Great Oolite Group becomes even more complex compared to the succession in the West of England. McKerrow and Kennedy (1973) record the generalised sequence below:

Lower Cornbrash	2.7 - 3.0m.
Forest Marble Formation	5.7 - 9.0m.
White Limestone Formation	c.11.0 - 16.0m.
Hampen Marly Formation	4.0 - 9.0m.
Taynton Limestone Formation	4.5 - 7.5m.
Sharp's Hill Formation	4.0 - 5.8m.
Chipping Norton Formation	11.0 - 21.0m.

Thus McKerrow and Kennedy have raised the status of the units formerly known as, for example, the Chipping Norton Limestone, and Sharp's Hill Beds to that of Formations to conform with the modern lithostratigraphic practice. There seems no reason why this practice should not be extended to the Malmesbury and Bath areas and that clearly recognisable rock units such as the Acton Turville Beds and perhaps the Upper Rags could not be given an official lithostratigraphic title. They would preferably be defined as Formations because, if described as Members, there is an implication that they form part of another well defined, clearly recognisable rock unit which could be described as a Formation. It is not my opinion that this is true of the Acton Turville Beds and Upper Rags at present.

The increasingly complex facies sequence in the Oxford District

probably reflects the increasing proximity of the London Landmass, and thus increasingly shallow water conditions in the district. There is certainly evidence of subaerial emergence at the top of the White Limestone Formation and many of the other units show clear evidence of very shallow water conditions during their deposition (Palmer 1973, 1978)..

In the Northampton and Buckingham areas, the Forest Marble passes laterally into the Blisworth Clay Formation which is a sparsely fossiliferous clay with occasional rootlet horizons. Faunas recorded include 'Estheria' by Green (1864), and Viviparus, Neomiodon and Valvata have been recorded from Newport Pagnell (Casey, 1959). These faunas indicate conditions of reduced salinity and this is almost certainly related to the proximity of the London Landmass. It has been suggested that the Blisworth Clay may represent nearshore swampy conditions (Palmer, 1978).

Thus the Forest Marble Formation is one of the most extensive (and widespread) Formations within the Great Oolite Group, only surpassed in its areal extent by the Lower Cornbrash Formation, which immediately overlies it throughout the area.

Historical development of the stratigraphy of the Formation and its chronostratigraphy.

1. Historical development of the stratigraphy.

The Formation was first referred to by William Smith in his manuscript table of 1799, a "Table of the order of strata and their embedded Organic Remains in the vicinity of Bath examined and proved prior to 1799". The name Forest Marble was derived from the Forest of Wychwood, Oxon, where the coarse shell-detrital calcirudites were quarried for building stone and ornamental purposes towards the end of the eighteenth century.

It is clear that Smith intended the name to refer only to the calcirudites within the Formation as he gave other names to other lithological units now included within the Forest Marble Formation. The Bradford Clay was referred to as the 'Clay above the Upper Oolite' and he also referred to the Hinton Sands as a separate unit (Townsend, 1813). In a table made in 1819 he distinguished the Forest Marble from a clay beneath the Cornbrash and a clay above the Great Oolite (Arkell, 1931, p.263). Thus he recognised that what is now regarded by many as the Forest Marble Formation falls naturally into three lithological units in the Bath district.

Oppel (1857) placed the Forest Marble in the brachiopod zone of Terebratula lagenalis, along with the Cornbrash. This zonation was not practical in England however, as the index fossil is restricted to the Upper Cornbrash and is not found anywhere in the Forest Marble (Engleheart, c. 1925). Oppel separated the Forest Marble from the underlying Bradford Clay, which he placed in the zone of Terebratula digona (= Digonella digona). He does not appear to have distinguished the argillaceous and arenaceous lithologies between the Forest Marble calcirudites and the Cornbrash as belonging to either Formation.

Ramsay, Aveline and Hull (1858) give a description of the Forest Marble including "all the strata between the white limestone and the Cornbrash", this referring to the succession in Wiltshire and Gloucestershire.

Woodward (1894) pointed out Oppel's error and stated that Smith regarded the Forest Marble as being overlain by the Cornbrash. The Bradford Clay, considered by Hull (1857) and Lonsdale (1832) to be the local basement bed of the Forest Marble, was included within the Forest Marble by Woodward. He suggested that the Bradford Clay Fossil Bed marked the base of the Formation in the Bath area and the Boueti Bed marked its base on the Dorset coast. His definition of the limits of the Formation is still generally accepted, at least from the Dorset Coast to the Mendip Hills.

Woodward recognised that the Formation fell in the Clydoniceras discus ammonite zone but suggested that the index fossil was too rare to be of practical use in identifying strata. He proposed that an alternative index fossil would be Waldheimia (= Digonella) digona.

He used the term Bradfordian to refer to the Forest Marble and Bradford Clay. This term was first used by Lycett (1863) referring to beds at Islip containing a fauna very similar to that of the Bradford Clay of Bradford-on-Avon. It seems certain that Lycett intended it to refer to rocks between the Cornbrash and the lowest occurrence of a fauna similar to that in the Bradford Clay Fossil Bed. The term Bradfordian was also used by Buckman (1927) in a lithostratigraphic sense to apply to marly clays containing a bradfordian fauna occurring towards the middle of the Formation in the Cotswolds, above his Wychwoodian subdivision.

The Bradford Clay Fossil Bed was already well known by this time (Townsend, 1813; Cunnington, 1860). This fauna and those of similar

composition are referred to in this thesis as bradfordian, without a capital letter to distinguish them from the stratigraphic terms which will, it is hoped, lapse except in the type area, following Palmer (1974).

Sylvester-Bradley (1957) considered the following species to be representative of the fauna and important in its recognition:

Digonella digona (J. Sowerby)

Eudesia cardium (Lamarck)

Dictyothyris coarctata (Parkinson)

Apiocrinus parkinsoni (Schlotheim)

Palmer considered the taxa below to be representative:

D. digona

Radulopecten vagans

E. cardium

Terebellaria ramosissima and other

D. coarctata

branching ectoprocts

Cryptorhynchia sp.

Apiocrinus sp.

Avonothyris bradfordensis

'Cidaris' bradfordensis

Oxytoma costatum

Additionally, the oysters Praeexogyra hebridica (Forbes) and Catinula ancliffensis are extremely common faunal elements.

Such faunas are common in the Forest Marble Formation as a whole, particularly south of Bath, though they are not found at the top of the succession in this area. They occur in the Boueti Bed, the Bradford Clay Fossil Bed and the Digona Bed and at many other horizons. The Digona Bed occurs immediately above the central bioclastic limestones in the Weymouth Anticline, some 18m. above the Boueti Bed.

It must be emphasised that the bradfordian faunas are not confined to the Bradfordian as defined by Woodward or Buckman. They occur in the Upper Rags of the Bath area (Penn and Wyatt, 1979) and extensively in the middle and upper Bathonian of Normandy (Palmer, 1974). The

fauna cannot therefore be used to define a chronostratigraphic unit represented by part of the Forest Marble Formation as apparently suggested by Woodward (1894). The historical development of the stratigraphy is summarised in Fig. 6.

In the last decade the problem of defining the base of the Formation in the Bath district has received considerable attention.

Green and Donovan (1969) redefined the base of the Formation at the top of the Bradford Coral Bed in the Bath area. North of the limit of the Bradford Coral Bed, the base of the Formation is marked by a great increase in argillaceous and arenaceous sediment. The Bradford Coral Bed is approximately 3.5m. beneath the Bradford Clay Fossil Bed at Bradford-on-Avon.

Penn and Wyatt (1979) include the Upper Rags within the Forest Marble in the Bath area, as they note that bradfordian faunas persist below the level of the Forest Marble as previously defined and because they believe that the base of the Upper Rags forms the more natural mapping boundary between the Great Oolite and Forest Marble, Fig. 58 .

In detail Penn and Wyatt (1979, p.46) state that survey mapping by Welch and Cave in the Tormarton-Biddestone area of the Bath One-inch sheet has shown that the Upper Rags correspond to the Acton Turville Beds of Acton Turville Railway Cutting, which are of similar facies and include patch reefs at the base. The Acton Turville Beds have been shown to pass northwards without perceptible break into limestones of the Forest Marble Formation in the Malmesbury area (Cave, 1977). In these more northerly areas the base of the Acton Turville Beds is more definite than the top and hence provides a more natural mapping boundary between the Forest Marble and Great Oolite. Strong supporting evidence for this usage is provided by the first occurrence of the Bradford Clay fauna which is present at the base of the Upper Rags

of Bath and the Acton Turville Beds and the Basal Limestones of the Forest Marble Formation further north.

They go on to point out that beyond the southern limit of the Upper Rags at Baggridge Hill, equivalent beds in the mudstone facies differ from the underlying unit they call the Frome Clay (= Upper Fuller's Earth of Torrens, 1980) but resemble typical Forest Marble mudstones in the occurrence of silty or sandy wisps and lenses, fine lignitic detritus and sand-filled burrows.

Thirdly they state that the stratigraphical level of the C4/D foraminiferal faunule boundary at Frome occurs just below the base of mudstones equivalent to the Upper Rags, corresponding to its position just beneath the base of the Forest Marble Formation on the Dorset coast (Cifelli, 1959).

Taking the third point first, it would seem clear that if the C4/D foraminiferal faunule boundary is to be used for stratigraphic purposes it should be used in a chronostratigraphic or biostratigraphic sense rather than a lithostratigraphic one. In what sense the basal Forest Marble marls south of Baggridge Hill are "equivalent" to the Upper Rags is not made clear by Penn and Wyatt.

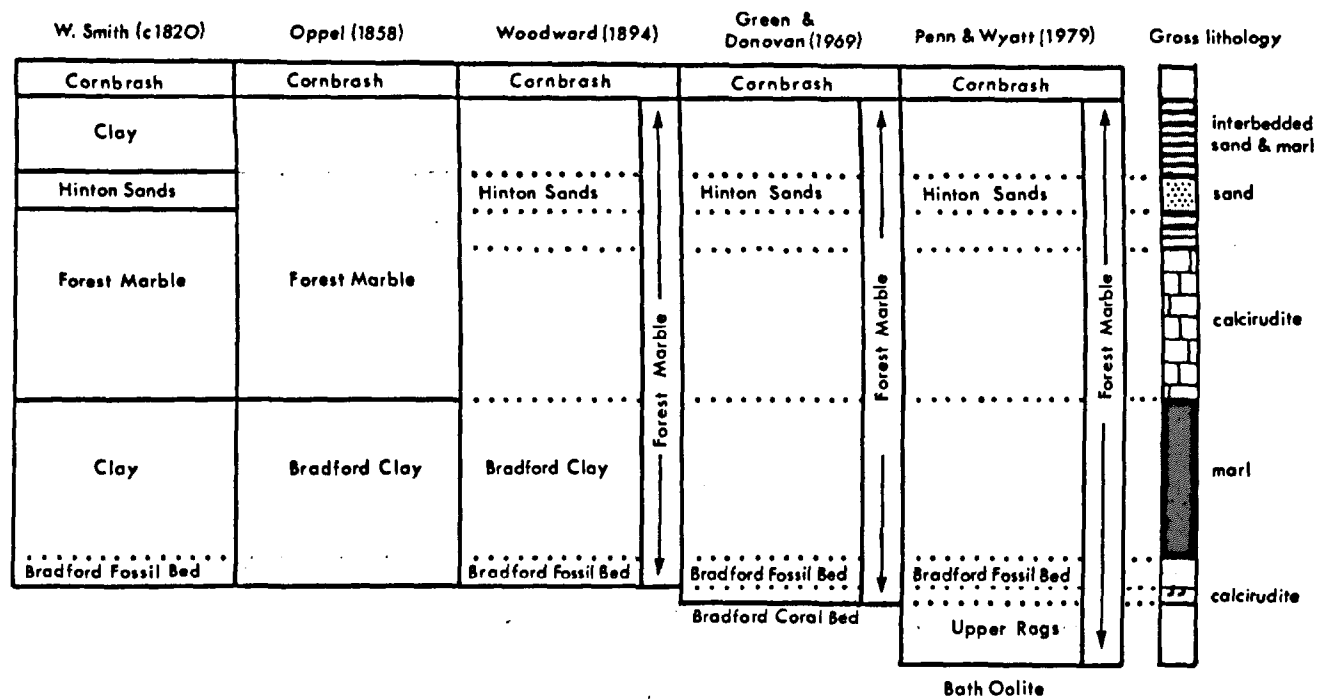
Further to this, it is obvious that the reason the marls "equivalent" to the Upper Rags south of Baggridge Hill resemble typical Forest Marble marls is because they are part of the Forest Marble Formation. Arguments as to what the Upper Rags pass into laterally are not wholly relevant to the lithostratigraphic status of this unit. In addition, faunal evidence, such as the occurrence of bradfordian faunas, is a criterion of low priority in the definition of lithostratigraphic units.

Much more relevant to this question is the statement "The Upper Rags can readily be traced as a recognisable unit over the whole area

as far south as Baggridge where, like the Great Oolite, they pass into a mudstone facies". (Penn and Wyatt, 1979, p.46). This certainly suggests that reasons for grouping the Upper Rags with the Forest Marble rather than the Great Oolite sensu Green and Donovan (1969) are at least arguable.

If the Great Oolite Group is accepted as a lithostratigraphic unit, the question could be reduced to an appraisal of whether the Upper Rags should constitute a member of the Forest Marble Formation or another, lower, Formation or whether they warrant the status of an individual Formation. As they contain some degree of internal lithological homogeneity and have distinctive lithological features that constitute a unity by comparison with adjacent strata and they form a unit which is mappable at the earth's surface and traceable in the subsurface, they have all the attributes of a Formation (see Holland et al., 1978).

In this study, no examination of the Upper Rags has taken place except for purposes of comparison with the Forest Marble sensu Green and Donovan as, at the time the research was in progress, the base of the Formation was defined as at the top of the Upper Rags.



..... named lithological units within the Forest Marble
 unnamed lithological units within the Forest Marble

Figure 6. Correlation of lithological units recognised by various authors in the area around Bradford-on-Avon

Regional Considerations.

Although the Forest Marble succession to the north of the study area is not well known except around Oxford, it is possible to draw at least a few tentative conclusions about its relationships to the sequence south of Bradford-on-Avon. However, this can only be done if reference is made to certain stratigraphic problems in the definition of the base of the Formation.

The source of these problems is the development of the so-called Basal Limestones of the Forest Marble (e.g. Cave 1978 p151) to the north of the study area. These include the Acton Turville Beds, part of the Kemble Beds and the Upper Rags (fig 7).

Buckman (1924, p.28) discussed the Forest Marble exposed on the Wootton Bassett to South Wales railway line and coined the name Acton Turville Beds for Limestones assigned by Reynolds and Vaughan (1902, pp 742-747) to the "Great Oolite of Bradford Clay facies". Arkell and Reynolds and Vaughan clearly considered the outcrop to be of Great Oolite (limestones) lithology but to contain a Bradford Clay fauna. Thus in the light of our knowledge of the wider distribution of bradfordian faunas there may be less evidence for the inclusion of the Acton Turville Beds in the Forest Marble Formation.

The Acton Turville Beds pass southwards into the Upper Rags (Cave, 1978 p.150) and to the north and northeast they pass into limestones described by Woodward (1894) as Kemble Beds. The Acton Turville Beds have been mapped as terminating in the vicinity of Dunkirk (ST 789833), though their junction with the Kemble Beds is not sharply defined. The lithology is more shell-detrital and slightly less argillaceous in this area (Cave, 1978 p.152).

All the above units can be considered to fall within the so-called Basal Limestones of the Forest Marble, though the term Kemble Beds has been used in different ways and is surrounded by the utmost confusion. Woodward coined the term Kemble Beds for "false-bedded oolites (which) occur above the white limestones of the Great Oolite" (Woodward, 1894 pp 249-250). He considered

SW

NE

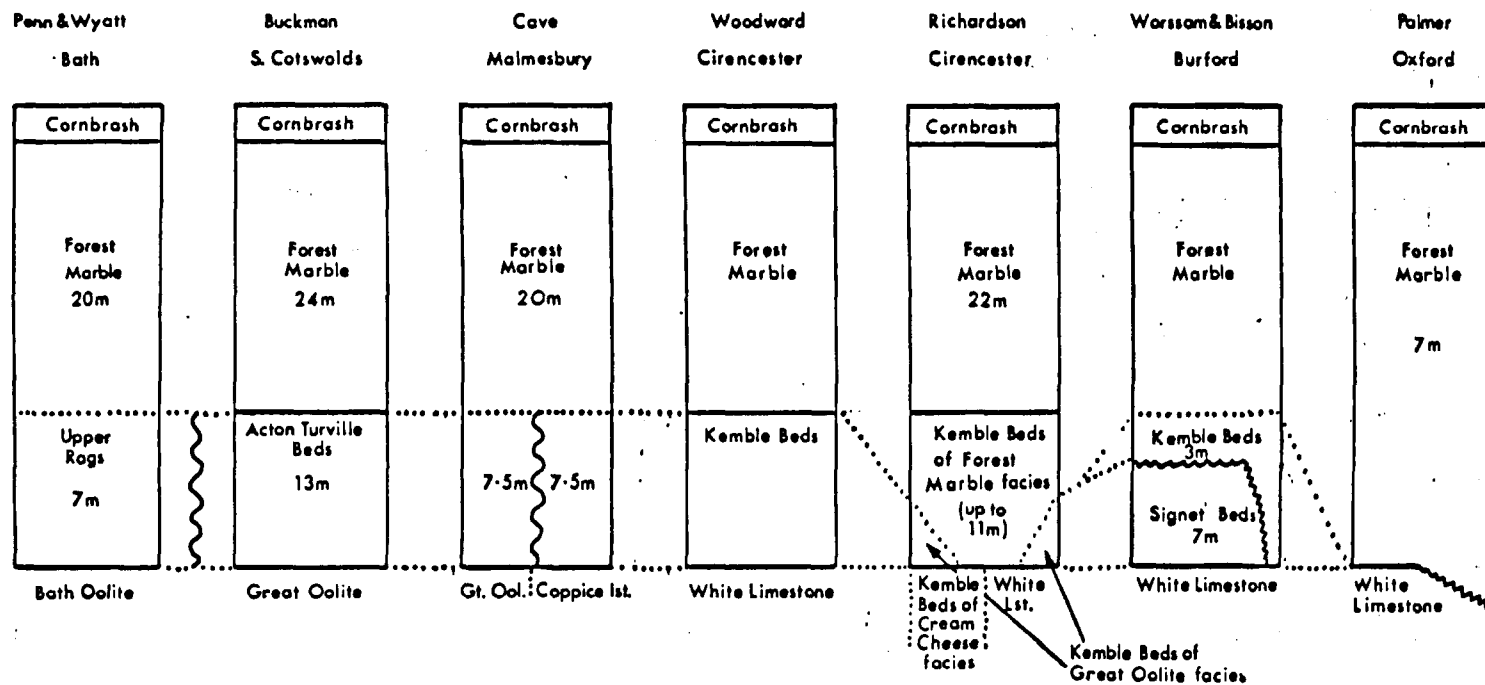


Figure 7. Proposed correlation of lithostratigraphic units used by various authors in the area between Bath and Oxford.

them to be part of the Great Oolite rather than the Forest Marble, though it is not immediately clear whether he came to this conclusion because in places they occur stratigraphically below "Bradford Clay" faunas or because they differ lithologically from the Forest Marble. However, he made two important observations:

- 1) Northeast of Cirencester the Kemble Beds appear to be overlapped by the Forest Marble.
- 2) He agreed with J. Buckman (1858) that in the area around Minchinhampton, Tetbury and Cirencester strata occur between the Great Oolite and the Forest Marble that should be placed in the Great Oolite rather than the Forest Marble in which they had been placed by Hull (1857). According to Buckman's description these are "Yellowish oolites with more or less oblique lamination, sometimes separated into two or more stages with thin partings of sand or marl, occasionally a hard compact freestone throughout". (Buckman, 1858).

If Woodward's Kemble Beds can clearly be identified with the beds described by Buckman, then it is clear that he considered them to be separate from the Forest Marble on lithological grounds.

The problem of the Kemble Beds appears to have confused even Arkell, who considered them to be part of the Great Oolite (limestones) and separate from the overlying strata which contained a "Bradford Clay" fauna, at least in places (Arkell, 1931 p.569). He acknowledged that strata of "Forest Marble facies" occurred both above and below horizons containing bradfordian faunas and therefore suggested that the term Forest Marble should be removed from the stratigraphic literature and that all strata below the "Bradford Clay" faunas and above the Athelstan Oolite or White Limestone should be referred to the Kemble Beds. All strata above the faunas was to be described as Wychwood Beds. He was well aware however, that there are areas in which "Bradford Clay" faunas are not present at all and that in these areas the "line of demarcation is difficult if not impossible" (Arkell, 1931 p.594).

Arkell's basically chronostratigraphic subdivision of the problematic

horizons was based on the assumption, now shown to be erroneous, that bradfordian faunas are all more or less synchronous. In fact the litho-stratigraphic boundaries probably cut across his proposed line of demarcation between the Kemble and Wychwood Beds.

Richardson (1933) followed Arkell to some extent, in that he considered that the "Bradford Clay" fauna was useful chronostratigraphically. However, he recognised Kemble Beds of three facies; Cream Cheese facies, Forest Marble facies and Great Oolite facies. The Kemble Beds of Cream Cheese facies are now considered to be the lateral equivalent of the White Limestone (Barker, 1976 p.1:15). A very important point noted by Barker (1976, p.1:13) is that wherever Kemble Beds of Forest Marble facies occur with either of the other two facies, the former overlie the latter. Thus if one disregards the supposed time equivalence of these three facies (based on the false assumption of the chronostratigraphic significance of the bradfordian faunas) it seems probable that lithostratigraphic units, i.e. the Kemble Beds of Forest Marble facies and those of Great Oolite facies, could be separated. This is supported by Richardson's description of sections in the Cirencester district (Richardson, 1933 pp. 49-74, pl.V).

Worssam and Bisson (1961) also considered that the Kemble Beds could be divided into two units in the area around Burford; a lower unit, the Signet Beds and an upper unit, the Kemble Beds (presumably to be included in the Forest Marble). Their Signet Beds have a distinctive lithology being "fine-grained oolites with white or yellowish ooliths and finely broken shell fragments scattered through a pale grey groundmass" (Worssam and Bisson, 1961 p. 97). The overlying unit of Kemble Beds channels into the Signet Beds and has removed them entirely in places, suggesting a break in deposition between Signet Beds and Kemble Beds.

Some controversy exists over the status of the Signet Beds. Barker (1976.) considers that the upper subdivision of the Kemble Beds is part of the Forest Marble and that its erosional relationship to the Signet Beds extends to the White Limestone in the Wiggold Railway Cutting and at Bunkers Hill, Shipton-

on-Cherwell, where it cuts through the Aphanoptyxis bladonensis bed of the White Limestone. However, Palmer (1974) considers that the Signet Beds are a distinctive facies of the Forest Marble in the Burford district rather than a distinctive lithological unit below it. In either case it is clear that the Signet Beds are of different facies from most of what is commonly acknowledged to be the Forest Marble.

Thus to the north of the study area there are a group of sediments lying between sediments of clearly Forest Marble lithologies and clearly Great Oolite (limestones) lithologies. On the basis of their lithological differences from the accepted Forest Marble and the presence of an erosional break in the area around Cirencester, I am extremely reluctant to include them with the other sediments of the Forest Marble Formation. It seems possible, moreover, that the base of the Forest Marble could be defined in purely lithological terms if exposure allows.

2. Chronostratigraphy of the Forest Marble south of Bath.

Ammonite evidence

Ammonite evidence assembled below is taken from an unpublished MS. of H.S. Torrens.

Occurrence of ammonites.

Bradford Clay of Bradford-on-Avon Two ammonites are known from here:

- a) Clydoniceras cf. hollandi (S.S.B.) (M.)¹ Leicester University Geology Department 35972. Canal Quarry, Bradford-on-Avon.
- b) Clydoniceras (Clydoniceras) hollandi (S.S.B.) (M.) Bristol City Museum 472. Bearfield, Bradford-on-Avon.

Digona Bed (Weymouth Anticline) Two ammonites have been recorded from this horizon:

- a) Clydoniceras hollandi (M.) SM 47110,² found loose on the shore of the Fleet beneath the Digona Bed outcrop by J.D. Hudson, Sedgwick Museum.
- b) Clydoniceras sp. juv. Stony Heaps Plantation. P.C. Sylvester-Bradley collection.

Three ammonites have been found in the Boueti Bed:

- a) Clydoniceras (Delecticeras) sp. juv. (M.) S.M.J. 46367,² Thornford pipe trench, near Sherborne, in situ.
- b) Clydoniceras (Delecticeras) cf. ptychoporum (Neumayr) (M.) S.M.J. 19884,² Langton Herring, Dorset.
- c) Cadomites or Polyplectites sp. indet. G.S.M. Zr 1841. Boueti Bed, ex situ. Herbury Gore, Langton Herring. P.M. Earland-Bennet Collection.

In addition to these ammonites, an indeterminate perisphinctid nucleus was found in the central calcirudites at Watton Cliff approximately 15m. above the Boueti Bed, by M.J. Barker.

The ammonite evidence shows that the Digona Bed and Bradford Clay can be placed with some confidence in the hollandi subzone of the

¹ (M) signifies macroconch.

² Sedgwick Museum numbers.

Clydoniceras discus zone.

The Boueti Bed is placed in the Oppelia aspidoides zone. It is assigned to this zone as it contains a coarse-ribbed form of Delecticeras; (D. ptychophorum), which is very similar to C. (D.) crassum from the Aspidoides zone in N. W. Germany.

Correlation of the Forest Marble with other Formations in the Great Oolite, using ammonite evidence.

Wagnericeras arbustigerum (d'Orb) is known from the Freshford Facies of the Twinhoe Ironshot, indicating the Aspidoides zone (Torrens, 1980). Thus the indications are that the Boueti Bed and part of the Great Oolite limestones fall in the same ammonite zone and that consequently the Great Oolite (sensu Green and Donovan, 1969) is chronostratigraphically equivalent in part to the lower part of the Forest Marble Formation and in part to the Upper Fuller's Earth of south of the Mendips (Torrens, 1980).

Hallam and Sellwood (1968) state incorrectly that the Upper Fuller's Earth of Combe Hay, near Bath may be slightly younger than the Upper Fuller's Earth at Cliff End, Burton Bradstock, Dorset. In fact, if anything, the reverse is probably the case. Ammonites from the commercial Fuller's Earth bed at Combe Hay have been placed in the upper part of the Hodsoni zone, whereas the topmost Fuller's Earth at Burton Bradstock is assigned to the Aspidoides zone and contains coarse ribbed Delecticeras sp. (Torrens, 1969).

Sedimentological evidence presented in chapters 2, 3, 4 and 5 suggests that the Forest Marble Formation as a whole is probably regressive, younging in a southwesterly or southerly direction, that is in approximately the same direction as the Fuller's Earth. However, the ammonite evidence is too sparse to support this contention.

Chronostratigraphic correlations in the upper Bathonian are shown in figure 5.

CHAPTER TWO. FACIES ASSOCIATION A. Marl-dominated Facies Assn.

Introduction.

This facies association is composed largely of marl-dominated sediments. It is poorly exposed in the study area as it normally occurs sequentially below the limestones which form the prominent scarp associated with the Forest Marble and above the clays and shales of the upper Fuller's Earth. In practice it corresponds well with Arkell's (1947) lower lithological subdivision of the Forest Marble in Dorset. The majority of the work on the association took place at Watton Cliff, West Bay as this is the only unfaulted nearly complete natural section in the study area. Here there is no doubt as to where the base of the Formation occurs, and it is probably significant that this is the section in which a sequential organisation can most clearly be seen in the association.

The other section in which the association is well represented is that at East Cranmore Railway Cutting, near Wanstrow. Here there is considerable doubt as to where the base of the Formation should be defined and sections in the association are faulted.

These sections are supported by a large number of small outcrops and stream sections widely distributed within the study area and also by borehole logs and a certain amount of core, of which material from the Marston and Frome boreholes was examined.

The association is composed of facies 1 - 5. Of these, facies 1 - 4 are thought to be closely genetically related and to reflect deposition under increasingly high energy conditions. In practice it is not often difficult to separate thickness of these four facies, though as they form part of a continuum there are inevitably times when very thin developments of, for example, facies 3 may occur in sequences dominated by facies 2 and, at this level at least, the distinction between facies may become very difficult or arbitrary.

Facies 1.

Calcareous marlIntroduction.

This facies is the commonest in the Formation and appears to form the "background" sediment deposited when very low energy conditions prevailed. Marl occurs in all facies associations, though only as the matrix of the shell-beds of association B.

Description.

The term marl is used here according to the definition of Sudgen and McKerrow (1962): "Marl is a mixed rock containing clay minerals and aragonite or calcite, usually together with accessory components, such as silt, in lesser quantity. It is friable when dry and plastic when wet".

The composition of the facies is predominantly a calcareous Illite/Kaolinite marl with small amounts of accessory mica, clay size quartz and traces of chlorite. It also contains silt size quartz grains which occur mainly in wisps of millimetre scale thickness and a few centimetres length. These silt wisps may contain some very fine sand. Silt and sand grains may also occur sparsely scattered, apparently randomly, throughout the sediment or, more often, concentrated in bioturbation structures. Flat, elongate concentrations of sand and silt up to about 10mm wide and 5cm long occur in the field parallel to the bedding and are thought to be compacted horizontal burrows.

Analyses of samples taken through the complete section in the Formation at Watton Cliff, West Bay (SY 455907) at vertical intervals of one metre, indicate a considerable predominance of Illite over Kaolinite. Details of presence/absence data and methodology are given in Appendix 1.

This clay mineralogy is very similar to that recorded by Hallam and Sellwood (1968) for the underlying Upper Fuller's Earth clay at Cliff End, Burton Bradstock, but no traces of montmorillonite have been found within in the Formation.

Small pyrite concretions are occasionally found in the facies. At Watton Cliff, a thin development of concretions up to 4cm in median diameter is present approximately 1 metre above the base of the Formation, and at East Cranmore Railway Cutting, near Wanstrow (ST 694434) I have defined the base of the Formation by a horizon of bored and encrusted pyritic concretions. Apart from these occurrences, pyrite is largely confined to bioturbation structures, which are made more noticeable by it. This is particularly so in borehole cores. It is not common in the facies in general.

Small radially arranged groups of crystals of gypsum have been recorded from marls high in the succession at only one locality; West Hill, Sherborne (ST 642147). These are thought to result from weathering.

Silt and sand wisps are very variable in composition and texture. The silt itself is all quartzose. Sand grains rarely consist of microcline, which is noticeably better rounded than the quartz. The wisps are generally only a few grains thick and the majority are apparently grain supported. Very few of them show clear signs of grading. The bases may be sharp and flat, particularly if the wisps are very thin, but they have a tendency to be more irregular if the wisps are thicker. This may be the result of loading.

The facies contains a microfauna of forams and ostracods (Cifelli,

1959, 1960; Bate, 1978) and a small ichnofauna. The uniform nature of the lithology does not lend itself to the clear preservation of trace fossils and those recognised are chiefly vertical, oblique and horizontal endogenic silt-filled burrows. These are usually non-branching but occasionally branch at high angles to the main burrow system. They are not evenly distributed and show a tendency to be concentrated in units about 20cm. thick. Even where burrows are present they are seldom sufficiently common to completely destroy the depositional silt/clay lamination or to make strongly bioturbated units easily recognisable in the field. Following Osgood (1970) these burrows are assigned to Planolites and are interpreted as having been produced by deposit feeding Annelids. (Fig.8).

Where junctions with other facies, particularly sand lithologies occur, a much more varied ichnofauna, including dwelling burrows, is recognisable. This bioturbation is normally confined to the sand/marl interface, however, and is discussed below with the sand lithologies (p.42).

Macrofauna is extremely rare. In the lower part of the succession, thin shelled bivalve moulds are occasionally present.

Lignite is common throughout the facies. It is present largely as finely macerated fragments and stems as well as small chips of larger woody plants. There is a definite upwards increase in the amount of lignite present throughout the area. Towards the base, only a few scattered patches of very fine material are found concentrated on silt laminae whereas very large quantities, forming a prominent feature of the sediment, occur in the upper part of the succession, for example at West Hill, Sherborne (ST 642147). Large logs are never found in this facies; they are apparently confined to sediments formed under higher energy conditions. Bedding planes may be covered with a very

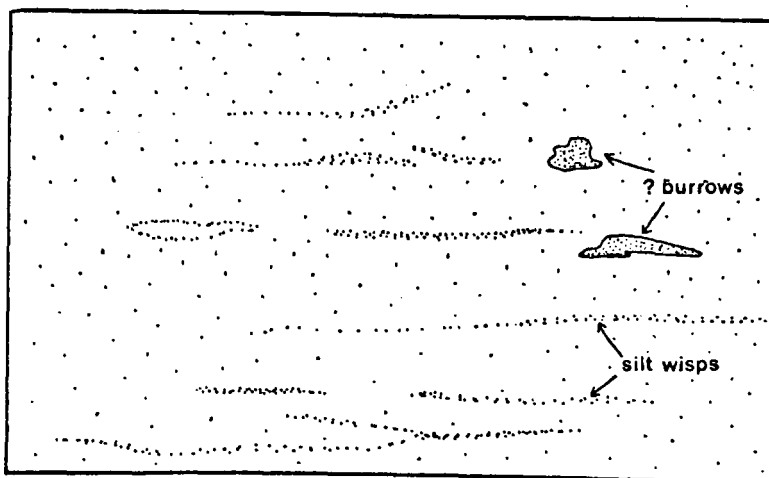


Figure 8. Facies 1, Calcareous marl. Note very irregular shape of poorly defined ?burrows and very thin silt wisps. These wisps usually have a marl matrix between grains and consequently do not weather out of the matrix as do the silt streaks of facies 2. Drawn from slice (x9). 2m above Boueti Bed, Watton Cliff.

thin layer of plant debris, this may occur as a drape on silt and sand wisps, or concentrated in burrows. Charophytes occur rarely among the plant material in this facies towards the top of the Formation at Watton Cliff.

Colour variation amongst the marls is considerable. This is most noticeable in weathered sections. The commonest colour is between light and dark grey, but olive green and brown marls are also present, usually in bands less than 20cm. thick. The significance of the colour variation is unknown. It is not clearly related to clay mineralogy or to organic carbon content. The relative lack of colour variation in borehole material suggests that it is likely to be related to weathering. The oxidation state of iron in the sediment and total iron content are important controls on subtle colour variations in marls.

The organic carbon content of five samples analysed was found to vary between 4.22% and 2.21%.¹ Material containing visible lignitic detritus was not analysed.

The bounding units of Facies 1 vary considerably as it forms the 'background' sediment against which the higher energy sediments were deposited. In different places it is in contact with all other facies in the Formation. It is particularly difficult to define the boundaries between the various facies of facies association A in the field as they are subdivided mainly on arbitrary levels of sand and silt content. Thick units of facies 1 are common immediately above the base of the Formation and rare towards the top, where they are commonly interbedded with thin sandstones.

Interpretation

The lithology of the facies is very similar to that of rhythmities (Reineck and Singh, 1972) which indicate rhythmic alternation in

¹ Methodology and results of all organic carbon analyses are presented in Appendix 1.

deposition of sediment. In association A where thick developments of this facies occur, the lack of sedimentary structures indicating transport by traction suggests that the sediment was probably deposited in quiet conditions from suspension. Deposition of the marl is likely to have occurred below normal wave base, the wisps of silt being deposited from suspension clouds, perhaps induced by storms. The concentration of silt into wisps suggests that deposition was slightly irregular and may reflect temporarily higher turbulence at the sediment/water interface which might have winnowed the wisps as they were deposited.

Similar thinly interlayered sediments have been reported from several modern environments. These include tidal flats (McKee, 1965), the foresets and bottomsets of the Rhine delta in Lake Constance (Forstner et al., 1968) and in restricted bays (Seibold, 1958).

Epifaunal suspension feeding organisms are almost entirely absent suggesting that the benthonic environment may have been hostile to them. Palmer (1974) has suggested that at the time of deposition, Forest Marble marls in Oxfordshire were probably particularly soft and 'soupy', though no evidence is advanced to support this hypothesis. It is suggested below that the lack of fauna in the facies is due to an unsuitable relationship between grain size and organic carbon content of the sediment perhaps combined with a very soft substrate at times.

Very soft substrates affect benthonic organisms in a number of ways. Firstly there is an increase in the proportion of deposit feeders relative to suspension feeders (Davies, 1925). This probably occurs because the low level of turbulence necessary for the deposition of clay size particles also favours the deposition of finely particulate organic matter. Within any given depositional environment, the fine-grained sediments always have a higher organic matter content than the

coarser ones (Trask, 1955). This organic matter serves as a food source for deposit feeders. Another important source of food in fine-grained sediments may be dissolved organic matter which becomes adsorbed onto clay mineral grains.

A very soft substrate does not provide any suitable attachment sites for the larvae of epifaunal suspension feeding organisms and thus prevents their development (e.g. Segrove, 1941; Walker, 1974). Growth of many established suspension feeders may be severely inhibited by the intake of large amounts of fine sediment drawn in during feeding which must be separated from food particles and then expelled as pseudo-faeces, with considerable energy loss. In this respect oysters are at a considerable advantage (Stenzel, 1971).

The rate of water renewal is of prime importance to suspension feeders, as the water they have used must be continuously replaced if they are to have sufficient food supply. Thus, all other factors being equal, the higher the current velocity, the greater the amount of usable organic matter brought to the suspension feeders and hence the larger the suspension feeding component of the bottom fauna (Purdy, 1964, p.245). In soft sediments the fine grain size suggests little turbulence at the sediment-water interface and thus a low rate of movement of water past suspension feeders.

It is also well known that very soft substrates severely limit the movement of vagile epibenthonic animals both within and on top of the sediment. Some species may be specially adapted to this, for example Aporrhais serresiana (Purdy, 1964). It is interesting to note, in this connection, that no surface trails have been found in this calcareous marl facies.

Great difficulties are present in attempting to recognise ancient sediments of very high initial water content, though criteria have been

advanced by Rhoads (1970). It may be possible to estimate the initial water content by observation of burrow boundaries. Sediments of original high water content, i.e. greater than 60%, have very indistinct burrow boundaries as animals moving through them deform them thixotropically and only a narrow zone of sediment deformation occurs round the burrow. Sediments of original low water content have clearly defined burrow outlines and may show wide shear deformation haloes. However, these burrow types form the end members of a continuum so that only a rough judgement of initial water content may be possible from then. Also, silt-filled burrows form natural channels for percolating groundwaters in argillaceous sediments. This is bound to diagenetically enhance the clarity of the burrow outlines. Normally both types of burrow are present in sediments, probably indicating shallow burrowing in soft sediment and deeper burrowing in more consolidated marl.

Several different types of burrow preservation occur in the calcareous marl facies. The least well defined occur in the least silty sediment, and their outlines become clearer as the silt content increases. It is not clear whether this is a diagenetic effect or an original texture.

Rhoads (1970) emphasises the role of deposit feeders in re-suspending the top few centimetres of such sediment. In Recent sediments the nature of the sediment-water interface may be altered by deposit feeders to give an uncompacted fluid surface consisting largely of faecal pellets which are very unstable in the presence of weak bottom currents (Rhoads and Young, 1970). Faecal pellets are not normally recognisable in this facies, but in other lithologies in which faunas occur, faecal pellets are not uncommonly preserved in the insides of articulated shells where they are unaffected by compaction. Thus it is possible, if somewhat unlikely, that large parts of the facies were pelleted.

Very soft substrates may also result from a high sedimentation rate, for example in the Mississippi delta interdistributary bays (Bennet et al, 1976, p.329). Resuspension of clay particles here also occurs as a result of slight turbulence at the sediment-water interface.

Another factor, thought to be of major importance in limiting benthos in muddy substrates, is the relationship between organic matter content and particle size. Bader (1952), working on the marine environments around Mt. Desert Island, Maine, studied the relationship of bivalve density to organic matter content in the sediment. He found a precipitous drop in numbers of bivalves at about 3% - 4% wt. organic matter. This is probably due to the result of accumulation of toxic decomposition products produced by bacterial decay of organic matter and/or depletion of available oxygen in the sediment due to greatly increased bacterial activity.

Oxygen-deficient sea bottoms are well known to contain very low-diversity specialised faunas, but adult bivalves tend to survive for long periods when transplanted to oxygen-deficient environments. (Theede, Ponat, Hiroki and Schlieper, 1969). Mya, Scrobicularia, Cyprina and Mytilus survived for more than 3 weeks in O_2 -deficient seawater (0.15ml. O_2 per L.).

The relationship between the organic matter content of ancient sediments and of Recent muds is not well understood. Duff (1975) suggests that comparison of Bader's data and bivalve-dominated faunas in the Lower Oxford Clay of Central England may show that in some cases meaningful comparisons can be made. The amount of organic matter in ancient sediments is clearly affected by diagenesis (Purdy, 1964).

Bader's data also shows a curvilinear relationship with clay

content as well as organic matter content. This may be because the organic matter content of the substrate is closely related to clay mineral content because of adsorption effects or because of the relatively poor interstitial circulation of finegrained sediments. In the latter case, a small amount of toxic decomposition products would have an enhanced deleterious effect on life compared to a sediment from which these products might more easily escape (Purdy, 1964). Bader's data shows that no pelecypods were present in the sediment at a clay percentage of 83%. Walker (1974) points out that whilst this data applies to bivalves, there is no reason why it should not apply to any deposit-feeding taxon. This hypothesis is perhaps the one that can best be invoked to account for the absence of deposit feeding organisms, with the exception probably of specialised annelids, from the calcareous marls of the Forest Marble Formation.

The presence of flat-based silt lenses suggests that the marls were not always very fluid at the sediment-water interface but if they were sufficiently soft to prevent the establishment of pioneer epibenthonic suspension feeders then the relationship between organic matter content and particle size may have been sufficiently adverse to account for the lack of shelly infauna.

Diagenesis may also have played a part in the destruction of shelly communities if present in this facies. In the immediately underlying Upper Fuller's Earth in West Dorset, preservation of faunas varies enormously. Perfectly preserved partly aragonitic valves occur at Cliff End, West Bay in the Fuller's Earth Clay. Laminar aragonite is preserved in ammonites, nuculids and Bositra buchi (Rümer), whereas crossed lamellar aragonite in heterodont livalves has partly been dissolved (Jefferies and Minton, 1965). At Watton Cliff however, bivalves and belemnites are very rare in the Fuller's Earth, except as thin carbonate films on bedding planes.

Facies 2. (Fig 9).

Silt-streaked marl

This facies occurs in associations A and D. It is characterised by distinct silt and fine sand streaks in calcareous marl. These are of a thickness observable in the field, i.e. >2mm, and may be up to 1cm thick. They may be traced laterally for several centimetres though rarely for more than a metre. Silt streaks form up to 50% of the rock. There is no evidence of erosion at their bases, which are usually irregular due to minor loading. The bases are sharp. A poorly defined normal grading may be present. Silt and fine sand grains are >95% quartz and generally subangular to subrounded.

Horizontal endogenic silt-filled burrows are common. Rare meniscus lined burrows assigned to Siphonites are present; these may be of crustacean origin (Heinberg, 1973). Other oblique burrows with internal spreite up to 16mm long and 4mm in diameter have been observed in thin section. These are of uncertain ichogenus..

Rarely, thin shell fragments may be seen in section. These are usually poorly preserved, but are thought to be ostracod carapaces. Occasionally entire but worn ostracod carapaces occur on the tops of laminae. These have not been identified.

Finely comminuted lignite detritus occurs parallel to the bedding, generally in sparsely distributed patches.

Organic carbon contents of the two samples measured were found to be 0.9% and 4.4%. The increased range compared with facies 1 is probably a reflection of the high silt content of the samples.

The facies is very common throughout the Formation in the study area but is very difficult to distinguish in the field from facies 1. On fresh surfaces it is clear that boundaries with facies 1 are gradational and characterised by the presence of thicker silt and sand laminae occurring sporadically amongst silt wisps and gradually

becoming dominant over a vertical distance of perhaps 20 cm. Weathered surfaces, such as the lower part of the succession at East Cranmore railway cutting (ST 694434) are characterised by the presence of very thin loose sand and silt lenses which have weathered out of the marl and litter the outcrop. This is the chief characteristic by which it has been separated from facies 1 in the field.

Interpretation

The lithology indicates deposition from suspension in relatively calm submarine conditions similar to those envisaged for facies 1. The presence of thicker, more continuous silt laminae probably indicates a greater suspended load during periods of agitation and thus slightly higher energy conditions.

The presence of rare shell fragments and burrows with spreite, indicating dwelling and/or feeding traces probably reflects a change in environment to conditions more suitable for the existence of benthonic organisms than those of facies 1. It may be simply that increase in the firmness of the sediment allowed such burrows to be constructed and kept open but may also reflect a more favourable relationship between grain size and organic carbon content which would produce a less reducing environment at the sediment/water interface. Apart from increased grain size in the silt streaks, the presence of the silt streaks also indicates probably greater agitation at the sediment surface than applied in facies 1. This would lead to improved oxygenation of the water.

Discussion

Although the distinction of the facies in the field is not always easy, as it is simply part of a continuum between facies 1 and 3, it is important conceptually as it indicates the gradational variation in faunal and ichnofaunal content with increasing silt and sand content

of the sediment. As suggested above, this is probably a true increase in diversity as even in the marl-dominated facies bioturbation structures can be picked out by distortion of fine silt laminae. However, it must be pointed out that most trace fossils recognisable in hand specimen occur at sand/mud interfaces and thus that a preservational bias may also be present.

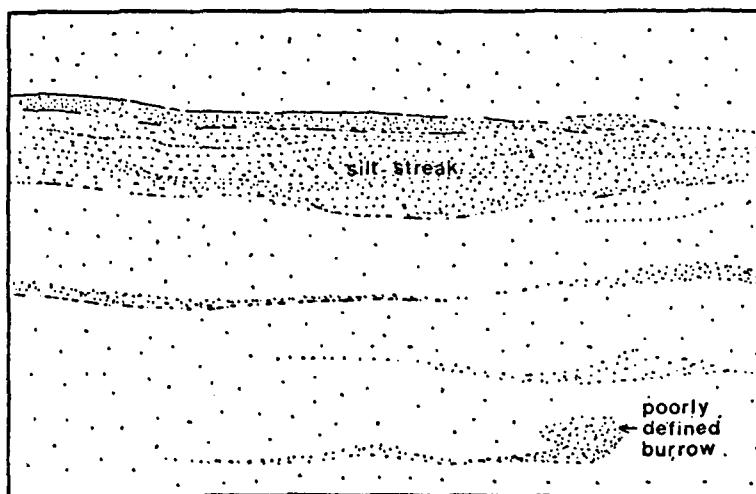


Figure 9. Silt streaked marl. Note poorly defined burrow picked out by silt concentration and poorly defined internal lamination within streak. Matrix is sparsely silty marl. Drawn from slice (x9). 7m above Boueti Bed, Watton Cliff.

Facies 3. Sand-streaked marl and interbedded thin rippled calcareous sandstones and marl

This facies is composed of parallel-laminated beds of sand up to 2cm thick, which occasionally have rippled upper surfaces, and thin elongate lenses or streaks of sand, interbedded with calcareous marl and/or silt.(Fig 10).

The sand is approximately 98% quartz with rare microcline, plagioclase and heavy minerals. Grain size is dominantly in the range 4.0 - 3.5 ϕ with about 10% by volume in the range 3.5 - 3.0 ϕ . It is subangular to subrounded and of high sphericity. Sand streaks are not laterally continuous over distances greater than about 3 metres, but rippled or parallel laminated sands usually extend for distances greater than exposure length, i.e. about 15m. maximum. The bases are usually sharp and may be loaded. Normal grading is occasionally present within the sands and silt drapes are common. Sand streaks may show low-angle cross-lamination in section if they have uneven top surfaces. This is seldom continuous to the bases of beds and usually only one or two cross-laminations are present.

Although clear grey marl laminae are present between streaks and lenses of sand, the lenses themselves and the silt drapes are a much lighter buff colour, probably due to the presence of considerable amounts of micrite between sand grains in the sediment, and thus the facies as a whole is usually clearly distinguishable from facies 1 and 2. The origin of this micrite is unknown.

Sparse shell fragments include oyster debris, crinoid fragments, serpulid tubes and ostracod carapaces. Other fragments are present but unrecognisable. All these are thought to be allochthonous. Finely divided lignite detritus may often be present parallel to lamination and often accumulates preferentially in ripple troughs.

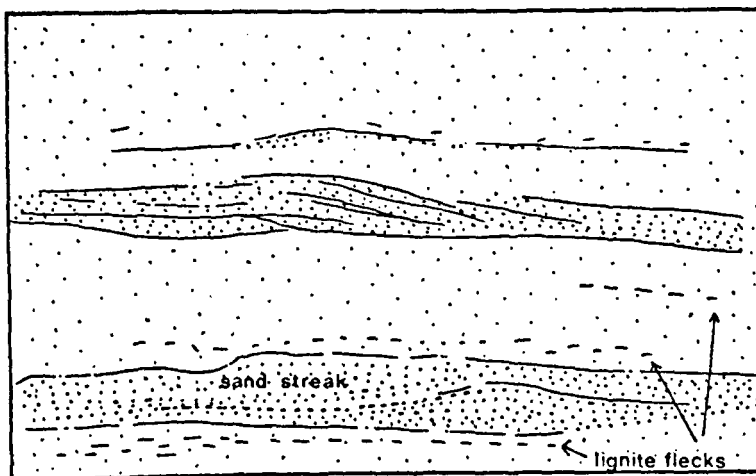


Figure 10. Facies 3, Sand streaked marl. Sand streaks may contain poorly defined cross laminations and have well defined bases. The matrix between the sand streaks is composed of silty marl. Note abundant lignite flecks parallel to bedding. Drawn from slice (x9). 9m above Boueti Bed, Watton Cliff.

The ichnofauna includes Teichichnus and burrows transitional between Teichichnus and Thalassinoides, with branches and well developed spreite. Neonereites and very small Cyrochorte up to 2mm. in maximum width are also present, particularly on rippled sands.

Interpretation

It is probable that the graded and ungraded layers were deposited from suspension against a background of marl sedimentation. It is well known that sand may be taken into suspension during storms in shallow epicontinental seas. The rare cross-laminae probably indicate minor transport of sand grains by traction, probably as a result of reworking of the tops of layers after deposition, as cross-lamination does not often appear to continue to the base of streaks. Similar sediments from the Carboniferous of County Cork are interpreted in a similar manner by de Raaf, Boersma and Van Gelder (1978). Similar coarse sand and mud layers interpreted as thin storm sand layers affected to variable degrees by wave action related to the same storm are described from the North Sea (Reineck and Singh, 1972).

The increase in diversity and number of burrow types to include some combined dwelling and feeding burrows, such as those forms transitional between Thalassinoides and Teichichnus may reflect an increase in firmness of the substrate. Similar burrows transitional between Ophiomorpha (which has many similarities to Thalassinoides) and Teichichnus have been recorded from the Eocene by Hester and Pryor (1972, p.686).

Facies 4. (Fig. 11).

Marly sandstone or sands

This is composed of extremely variably cemented fine sand very similar compositionally to that of facies 3, except that a small proportion of calcareous marl is present as the matrix between sand grains and, rarely, carbonate sand grains may be mixed with the quartz grains. Rarely it contains thin impersistent marl laminae and marl intraclasts. Its field appearance varies considerably depending on the pervasiveness of the carbonate cement. In places, e.g. in the stream section at Chanters Goyle, Birt's Hill near Halstock (ST 514830), well cemented sandstones with marl lenses and laminae are present immediately below the scarp of the central bioclastic limestones of the Formation, whereas at Watton Cliff, East Cranmore Railway Cutting, West Hill, Sherborne and Honeycombe Wood, Sherborne, only loosely cemented, yellow muddy sands are present.

Occasional faecal pellets and oolites are common, although they never form a significant proportion of the lithology. The thickness of sand beds is difficult to estimate due to pervasive bioturbation in most sections. In general it appears that bed thicknesses of 20 - 40cm. are common, although some of these may be bioturbated cosets. Where marl laminae are present the sand horizons have sharp bases, and well developed plane bedding and symmetrical and asymmetrical ripples are also occasionally present. Ripple-cross-lamination is normally developed throughout the beds indicating deposition by traction processes. One or two asymmetric ripples have been shown to be form-discordant.

Trace fossils are abundant - the assemblage being:

<u>Curvolithus</u>	Fritsch, 1908
<u>Rhizocorallium</u>	Zenkor, 1836
Planolites	Nicholson, 1873

<u>Neonereites</u>	Seilacher, 1960
<u>Gyrochorte</u>	Heer, 1865
<u>Favreina</u>	Bronniman, 1955

Rare immature Oxytoma are found in the facies at East Cranmore and indeterminate thin-shelled bivalves, Liostrea hebridica and Placunopsis socialis are also present.

Bounce, prod and tool marks occur on the bases of some sandstones. These are not commonly aligned perpendicular to wave ripple crests but are at an acute angle to the perpendicular.

Interpretation

This facies was probably deposited close to normal wave base. Preservation of ripples is good where bioturbation is absent, and most appear to be wave generated, though some form-concordant asymmetric ripples of unidirectional origin are definitely present. The occurrence of marly layers shows that higher energy conditions were still intermittent. The presence of bounce, prod and tool marks suggests that storm action capable of transporting large clasts may have been an important factor in the origin of the coarse fraction of the sediment.

Curvolithus has been interpreted as the product of an actively digging burrowing organism (Heinberg, 1973). Neonereites is a post-depositional endogenic burrow. It may be the irregular counterpart of Helminthoidea labyrinthica Heer, in a sandy environment (Seilacher, 1962). Planolites is a form genus; all non-branching approximately horizontal infilled endogenic burrows are assigned to this genus if they show no other distinguishing features. They may be produced by deposit-feeding annelids. Rhizocorallium has been thought to be the burrow of a deposit feeding animal (Veevers, 1962), possibly a crustacean (Sellwood, 1970). Favreina is interpreted as faecal pellets of crustacean origin. Gyrochorte is discussed fully below (p.167).

The presence of actively digging animals shows that the sediment was at least sufficiently stable for organisms to excavate it. Open burrows such as Rhizocorallium show that it was sufficiently stable not to collapse when tunnelled.

The increase in benthonic diversity is thought to be due to a combination of increased substrate stability and increase in grain size which would allow for better interstitial circulation and consequently a less hostile environment for both suspension-feeders and deposit-feeders. The calcareous faunas are rare and probably allochthonous as they are only found as single disarticulated valves. Their rarity probably reflects a true scarcity of byssally attached organisms. Shell fragments of Crustaceans thought to produce some of the trace fossils, are not found. This is the normal case and is probably due to the extremely rapid disarticulation and destruction of crustacean exoskeletons (Schäfer, 1962).

No allochthonous rock fragments have been recorded.

It is not clear to what extent, apart from the degree of cementation, this facies differs from Facies 17. The poor cementation and bioturbation at most localities has obscured the majority of structures and the sand mineralogy is extremely similar. However, as it can clearly be distinguished in the field from Facies 17, if only by subtle differences in colour and by the lack of concretionary cementation, this is sufficient for it to be separated as a facies.

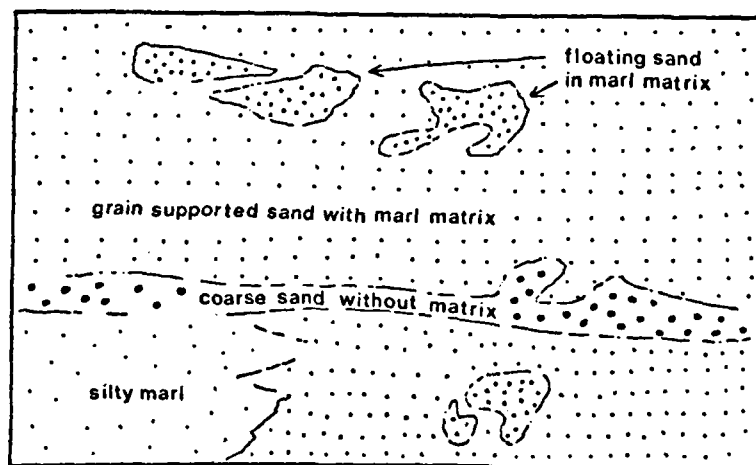


Figure 11. Facies 4, Marly sand. Note variation in matrix type and pervasive bioturbation picked out in coarse sand laminae. The floating sand grains in marl matrix probably represent poorly defined burrows. Drawn from slice (x9).

Facies 5. Graded sandstones and bioclastic limestones

This facies is common to associations A and D and is composed of graded beds 2 to 10cm. thick, the lateral extent of which is almost always greater than outcrop width, i.e. >10 - 20m. The composition of the facies varies considerably and not all components are present in most examples. Ideally, each bed is composed of a basal bioclastic and intraclastic shell lag overlain by a graded sand layer, which is in turn overlain by a silt drape. Great variation occurs in each of these layers. Basal shell lags may be up to 4cm. thick but are normally composed of a single lamina of convex-up shell fragments and marl intraclasts. Where a thick shell lag is present there is often a considerable amount of impure micrite in the matrix, whereas, when only a single lamina is present, it is usually overlain directly by sand and normally rests on marl. The dominant shell debris found is usually 'Liostrea' and Palaeonucula but more varied faunas are found in the thicker lags. Preservation varies a great deal but disarticulated and broken valves are common. Rounded shell fragments are occasionally present, but apparently unrounded shell debris is common.

The sand layer is normally the dominant layer and in the thicker units can be divided into a massive or parallel-laminated basal unit, often with marl intraclasts, overlain by a rippled unit which is often reworked. The massive or parallel-bedded unit may occasionally show low undulating laminae rather than true parallel lamination. The rippled unit, which is seldom more than 3cm. thick is usually composed of a single set of asymmetric or symmetrical ripples which is often reworked by an interfering ripple set (Figure 12).

The silt drape is usually only 2 - 3mm. thick but may be up to 1cm. thick. Rarely a micrite drape replaces it.

The bases of beds are nearly always sharp and show tool, prod and bounce marks and intense bioturbation. Irregular, flat, horizontal burrows are common, as are vertical, horizontal and oblique non-branching burrows. On the rippled top surfaces, Rhizocorallium and Neonereites are common in Association A. Surface trails possibly formed by gastropods also occur, e.g. at East Cranmore Railway Cutting (ST 694434). Trace fossils characteristic of Association D are described below (p.166).

Interpretation

The bounce-, prod- and tool-marks were probably produced by shell debris and intraclasts undergoing transport in high energy conditions. The shell lags are clearly allochthonous in origin and could not have been derived by winnowing from the interbedded facies as these are, in general, unfossiliferous. The fauna of the shell lags was predominantly byssally attached or cementing and was probably derived from adjacent environments. Intraclasts are invariably marl and are probably rip-up clasts. They are generally disc-shaped. The sand component is not usually graded as only fine sand appears to have been available as source material. In Association A the sand layer is usually relatively thin, probably reflecting a shortage of supply or distance from source.

The lithological features suggest that energy was at a maximum during the erosive stage and, as the current waned, the deposition took place successively of parallel-laminated sand and ripple cross-laminated sand. Following this, the ripple-cross-laminated layer was frequently reworked, presumably by a process associated with the high-energy event but differing from that which deposited the ripple-cross-laminated layer. As energy returned to normal, the silt or micrite drape would have been deposited from suspension.

This sequence of structures is common in sub-littoral sheet sandstones (Goldring and Bridges, 1973; Bridges, 1975; Kelling and Mullins, 1975). These have been interpreted as storm-dominated deposits. They can be simply explained by a model in which wind-driven waves produce currents sufficiently strong to transport shell debris which subsequently gradually reduce in power to deposit the sand layer. As wind speed drops waves would gradually cease to produce unidirectional currents and a more orbital motion would be induced to produce interference ripples (Johnson, 1978). Thus wave- and interference-ripples are probably intimately associated with the same event as the parallel lamination or unidirectional cross-bedding rather than post-storm reworking.

Wind-driven currents sufficiently competent to transport coarse sand and produce sand waves are known (Boggs, 1974), (Levell, in press) and thus semi-permanent currents or tidal currents need not be invoked to account for the production of the unidirectional cross-lamination or parallel-lamination.

Sequences in Facies Association A

The best natural exposures in the association are at Watton Cliff (SY 455907) and East Cranmore (ST 694434), see figures 13, 14.

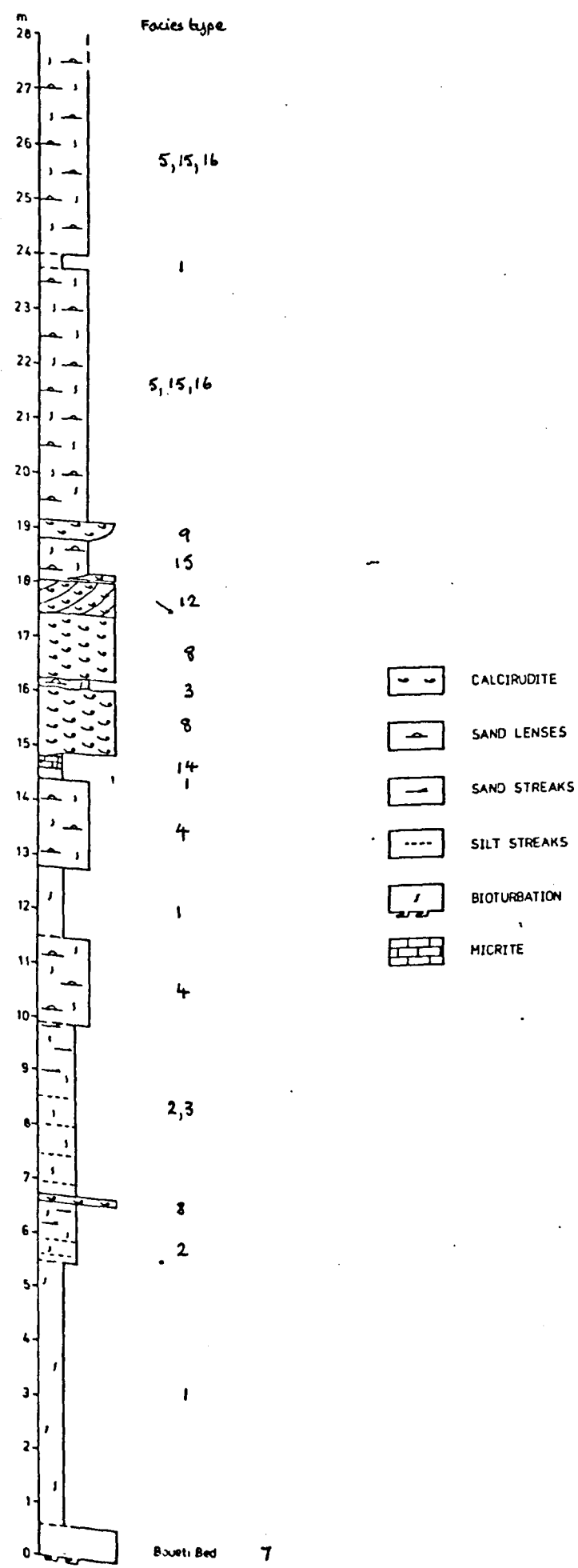
At Watton Cliff, the association occurs from the top of the Boueti Bed to near the base of the main calcirudite body. There is a clear coarsening up tendency in the sequence, though at a maximum at 8.1m. on the log, above which the sequence fines and then coarsens again. The second unit is coarsest approximately 1m. below the base of the calcirudites. The coarsening of grain size and increase in sand content is associated with an increase in sedimentary structures associated with tractional movement of sand, particularly wave and interference ripples.

The succession in the association at Watton Cliff is therefore considered to represent a broadly shallowing sequence, upon which a minor shallowing and deepening 'cycle' has been superimposed, probably due to local variations in submarine topography rather than to any regional effects.

At East Cranmore the coarsening upwards of the sequence is not so clear. A substantial sequence in the association is exposed beneath the calcirudite channel-fills which occur at 11.8m. in the log, but the thickness of this succession is uncertain. Though the base of this section has been taken at an horizon of bored, encrusted pyrite-rich concretions occurring at the western end of the cutting, this horizon is very poorly exposed - only half a dozen concretions have been found - and faults probably occur immediately above and below it.

Above the base of the sequence the majority of the succession is in facies 2, with a thin but useful marker horizon of facies 5. Above the development of facies 2 is a series composed dominantly of mixed carbonate and quartz silty sands with marl in the matrix,

Figure 13. Sections at Watton Cliff, West Bay, Dorset.



SECTION AT FAULT CORNER, SY 453908

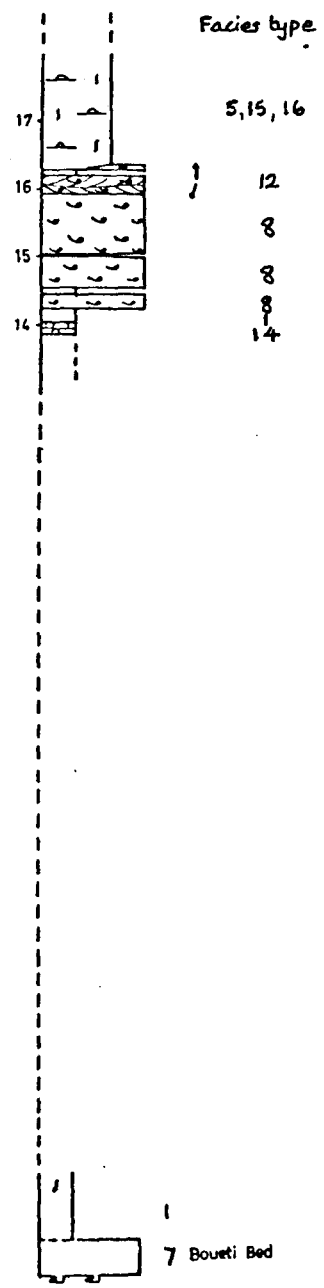
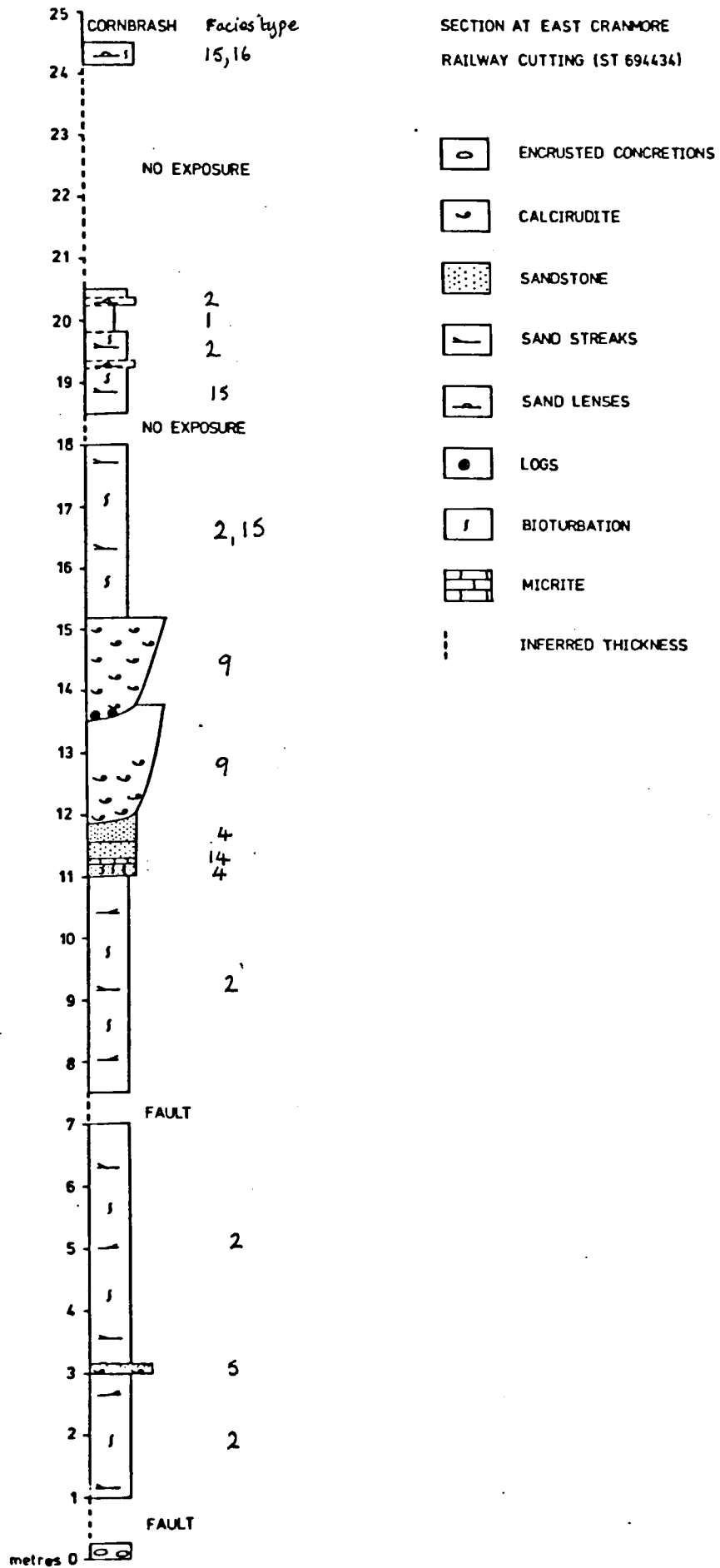


Figure 14.

SECTION AT EAST CRANMORE
RAILWAY CUTTING (ST 694434)



assigned to facies 4. These are cut into by the base of channels of association C. They are highly bioturbated and contain the trace fossils Thalassinoides associated with Favreina, the latter occurring in the Thalassinoides burrows. These Favreina are apparently identical to those in the White Limestone Formation at Wood Eaton Quarry, Oxon. and thus should probably be assigned to Favreina decemlunulata.

Thus the sequence coarsens upwards, though this is only obvious in the top 2m. of the succession (10 - 12m. on the log).

Coarsening upwards is the most typical tendency seen in the association in the study area. Stream sections at Swyre (SY 887537), Corscombe (ST 054519) and Meerhay confirm this. However, in at least two instances the association does not coarsen upwards. In the Baggridge No.2 and Faulkland boreholes the sequence coarsens then fines upwards with the development of muddy sands (Facies 4) with marl intraclasts towards the middle of the sequence.

Though there does seem to be a tendency for overall shallowing in the association in the study area in general, there is little evidence upon which to base a detailed interpretation of physical environmental factors such as depth and salinity. Mudcracks associated with fibrous gypsum bands occur at the top of the section in the association in Baggridge No.2 borehole, though these might have been caused by syneresis as easily as by subaerial shrinkage. I have not examined these mudcracks.

As described in the following chapter, autochthonous faunas occur as lenses interbedded within the association. These are considered to have been deposited in stenotopic conditions, though whether these conditions also occurred during the deposition of the facies association is not known.

If it is accepted that the Boueti Bed and Bradford Clay Fossil

Bed were deposited in relatively shallow, high energy conditions, the presence of considerable thicknesses of facies 1 marl immediately overlying them, followed in most cases by thick developments of other facies of association A, suggests that some deepening may have occurred after their deposition, followed by regression or basin-filling.

This begs questions about the contemporaneity of the hardgrounds and firmgrounds near the base of the Formation and also raises the problem of the developments of coarse calcirudites immediately above the Boueti Bed in the area around Bruton and Wincanton, at Redlynch (ST 697333) for example.

There is no clear geographical variation which suggests greater shallowing in one area than another. Thickness variation is difficult to interpret due to poor exposure. North of Wanstrow it is difficult to define the base of the Formation in the field and thus difficult to make judgements about the thickness of any developments of the facies association which may occur in the basal part of the Formation. Even where the Boueti Bed can be recognised, it cannot be assumed that the majority of the sediments between this horizon and the main developments of calcirudite are of facies association A even though this is the normal case. In general it appears that in Dorset and as far north as Wincanton there is a thick development of this association between the Boueti Bed and the main calcirudite bodies in the middle part of the succession, whereas in the Mendip area this is not clearly developed and the lower part of the Formation is composed of inter-bedded marl-dominated facies and calcirudite horizons.

The trace fossils are typical of marine environments in the Jurassic, but the absence of nektonic cephalopods cannot be ascribed to adverse benthic conditions, and their absence may be due to slightly reduced

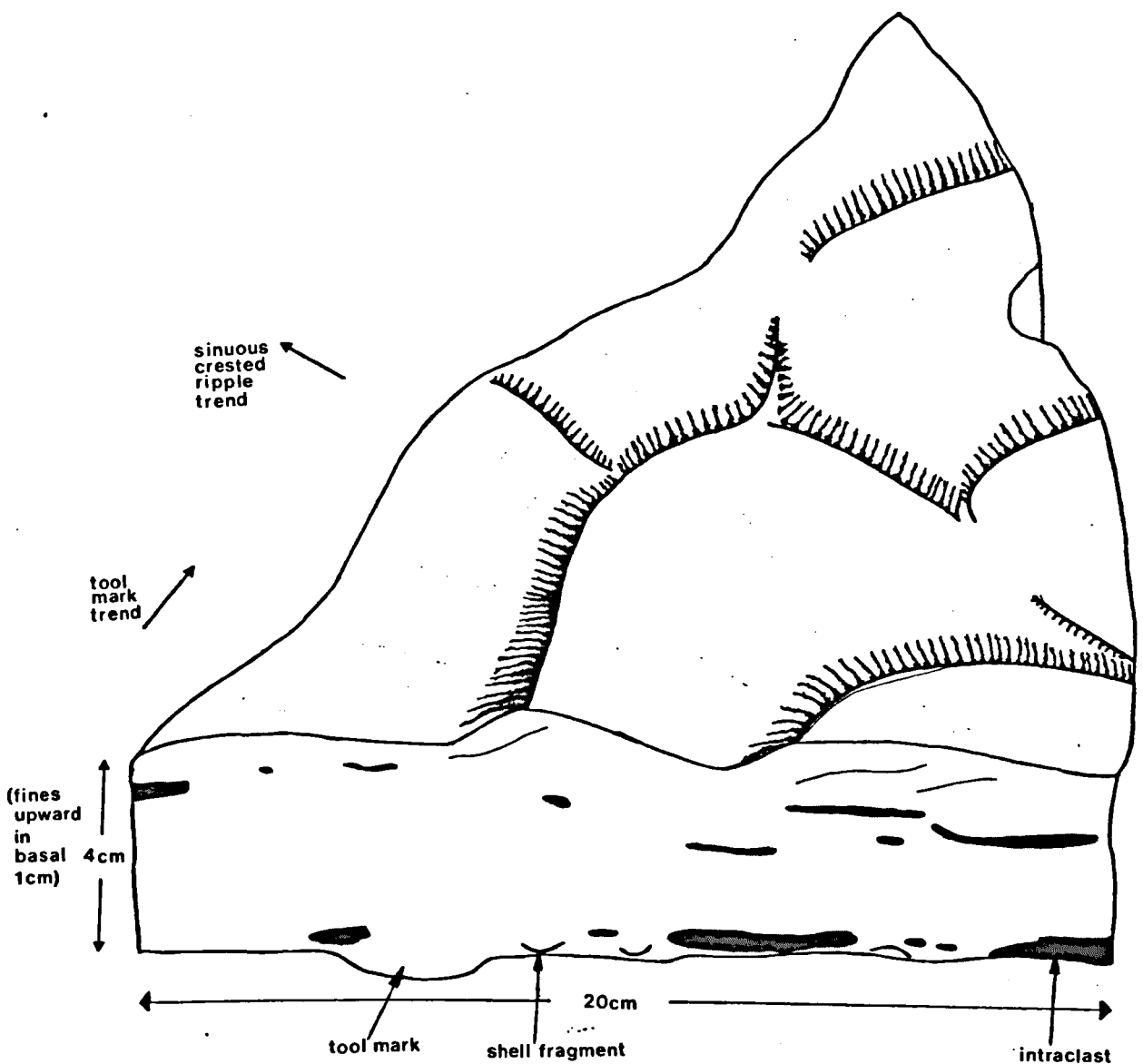


Figure 12. Typical example of facies 5 graded sandstone. Note large tool mark indicating direction of transport during storm maximum, and ripple orientation indicating direction of transport as storm waned. Drawn from specimen found loose at Watton Cliff.

salinity. Although cephalopods are amongst the most sensitive of organisms to reduced salinity, they occur at the present day in the Kattegat and Baltic Sea, though their diversity is reduced compared to the North Sea (Remane and Schlieper, 1971). Palmer (1974, p.242) suggests that the scarcity of cephalopods in the Great Oolite Group (Fuller's Earth excepted) is due to their adaptations to living in a deep column of water. However, I consider that some facies of the Forest Marble were probably deposited below wave base, though whether this should be considered to be 'deep' is uncertain.

CHAPTER THREE FACIES ASSOCIATION B

(Hardgrounds and firmgrounds facies association)

Introduction

The term "hardground" is used below to describe carbonate sediments which show evidence of early lithification, usually on the sea floor. In practice, Bathonian hardgrounds are recognised by the presence of borings which cut across grains and/or cement in the sediment, or by the presence on the surface of encrusting organisms which require a hard substrate upon which to secrete their shells (Palmer, 1974; Purser, 1969).

In the Formation in the study area, hardgrounds commonly pass laterally into horizons of highly burrowed calcareous marl or impure sandstones and siltstones, which typically show some evidence of consolidation but little evidence of lithification. The burrows are usually dominated by the Spongiomorpha-Thalassinoides group¹ but Rhizocorallium is also common. They are thought to have been excavated as dwelling and/or feeding burrows (Hantzschel, 1975; Sellwood, 1971). The fact that these burrows remained open with no obvious means of support, such as a mucous or pelleted wall lining, suggests that they were excavated in marls which were better consolidated than was normal in the Formation. These horizons are described below as firmgrounds.

The hardgrounds and firmgrounds show many similarities, particularly among their associated faunas. The faunas have been used extensively for correlation within the Formation in the past, (e.g. Woodward, 1894; Sylvester-Bradley, 1957). Because of the close association between their faunas and their genetic similarities, hardgrounds and firmgrounds are described below as a facies association.

¹ Taxonomy of the members of this group follows Fusich (1973)

Facies 6

Hardgrounds

The hardgrounds may be divided into those developed on lime mud substrates (micritic hardgrounds) and those formed on calcarenites (sparitic). These are described below as subfacies.

Subfacies 1. Micritic hardgroundsDescription

Micritic hardgrounds are developed in impure white to yellow finegrained limestones which are very similar to underlying and overlying marls and impure micrites which show no signs of early lithification. The hardgrounds are extremely well cemented and are considerably harder than the other micrites of the formation. They contain lenses and laminae of very fine quartz sand or silt and always show evidence of bioturbation. The carbonate content of the hardgrounds has not been determined but the insoluble residue of one specimen from the Boueti Bed at Birt's Hill, Halstock (ST 514083) was 2.8%.

The lateral extent and continuity of the hardgrounds is very difficult to judge, due to the occurrence of small, isolated exposures, but on the scale of the study area as a whole, development is patchy rather than laterally continuous.

The thickness of the lithified layer in the micritic hardgrounds varies between 1cm. and 14cm. The topography of the upper surface is often knobbly and irregular with a relief of up to 8cm. At a few localities, e.g. Honeycombe Wood, Sherborne (ST 636141), a planed upper surface which truncates borings and the encrusting layer may be present. The encrusting layer of the hardgrounds is discussed below (p.99). The lower surface of the hardground layers may simply pass downwards into grey or yellow micrite which may or may not have

been lithified soon after deposition, or may show development of the crevices described below.

The micritic hardgrounds may show evidence of more than one phase of syngedimentary cementation. Previously lithified irregular concretions may occur in the centre of the lithified layer, (fig.15). This figure shows a positive print of an acetate peel of the hard-ground immediately underlying the Boueti Bed at Birt's Hill, Halstock. The original lithified sediment towards the base of the specimen is bored by Trypanites. The boundary of this concretionary lump (arrowed) is picked out by the flat sides of Spongiomorpha paradoxa burrows which are encrusted by 'Serpula' sp. The Spongiomorpha producing organisms cannot have been able to excavate lithified sediment and thus the burrows abut against the early lithified sediment.

Crevices are sometimes developed beneath the hardground surfaces and may penetrate for distances of at least 12cm., usually approximately horizontally. This frequently results in small hand specimens obtained from field brash being encrusted on both upper and lower surfaces. The shape of the crevices is not clear as only the roofs of crevices have certainly been found, distinguished by faunas attached to the undersurfaces of loose blocks, e.g. fig.15. However some hardground blocks have been found which have only a very low diversity encrusting fauna composed entirely of serpulids. It is thought that these may be crevice floors as they are encrusted on only one side. The upper and lower surfaces may be distinguished by two criteria. Firstly, there is often a geopetal or sparry calcite infilling of lithophagid crypts in the roofs of crevices and secondly there is a marked polarisation of the attached and boring faunas into an upper surface and a crevice community. It is also notable that the lithophagid crypts tend to be smaller on the crevice surfaces. The polarisation

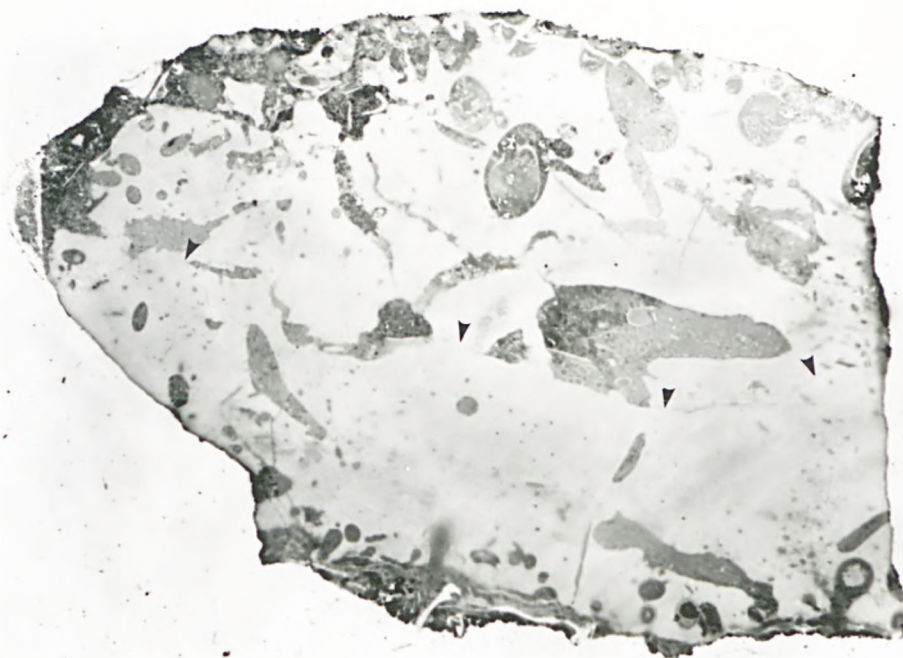


Figure 15. Boueti Bed hardground, Birt's Hill Halstock, showing Spongiomorpha burrows sharply abutting against early lithified lump (arrowed). Note encrusting of burrows, and small bivalve crypts in crevice rock towards base of photograph.
Acetate Peel, x 1.5

of attached faunas is described with reference to the Bradford Clay Fossil Bed hardground by Palmer and Fursich (1974). Traces of burrows produced before lithification of the sediment, preserved only as deflections in the bedding are usually present in the hardgrounds.

Very rarely elements of a shelly infauna may be found associated with micritic hardgrounds. On the east side of Herbury Promontory (SY 614807) an infauna similar to that of the unlithified micrites of facies association C is found in marl patches between concretionary lithified encrusted lumps of limestone and also partially incorporated into these lumps, see p.95. This fauna forms part of an ecological succession which occurred during hardground development and is discussed below (p. 99).

Discussion

It seems likely that the micritic hardgrounds developed from unlithified micrites and marls by a process of aggregation and enlargement of concretionary lumps which coalesced to form a continuous layer. The presence of burrowing episodes between periods of lithification suggests that cementation took place in several episodes and that conditions suitable for the formation of hardgrounds were temporarily interrupted by increased sedimentation. A similar process of lithification is thought to have taken place in some Chalk hardgrounds (Bromley, 1965), and in Recent hardgrounds in the Persian Gulf (Shinn, 1969, p.123).

The purity of carbonate sediment may have been an important factor in the initiation and progress of symsedimentary submarine lithification. Bausch (1968) and Zankl (1969) have shown that where the proportion of clay in calcilutites exceeds 2%, early recrystallisation is inhibited and compaction may occur on loading. Thus in impure carbonates the process of lithification may be slowed compared

to purer limestones or even prevented altogether.

If this inhibition of early recrystallisation is related to poor exchange of pore waters between the sediment and seawater it is possible that extensive burrowing may have had an opposite effect on the sediments, increasing the area available for exchange of pore waters and thus encouraging early lithification. It seems possible then that the patchy distribution of hardgrounds and their lateral passage into unlithified sediments may be, in part, related to carbonate/clay ratios in the substrates and possibly to burrowing activity.

The origin of the crevices in the sediment is thought to be related to the enlargement of pre-existing burrows (presumably Spongeliomorpha networks) during the cementation process (Palmer and Fursich, 1974). Similar crevices occur beneath Recent hardgrounds in the Persian Gulf, where vagile benthonic organisms contribute to their enlargement (Shinn, 1969).

The burrows in the eventual hardground formed a refuge for a variety of sessile organisms including Catinula, ectoprocts and serpulids. Serpulids occur up to 5cm below the hardground surface attached to the walls of Spongeliomorpha networks. This suggests that the burrows must have remained open during and after lithification. It has been suggested that some vagile organism must have occupied the burrow system after lithification to remove any sediment falling into it (Fursich and Palmer, 1975) but the nature of such an organism remains a matter for speculation.

The occurrence of planed surfaces on hardgrounds suggests local patches in which erosion was dominant towards the time of burial. Field brash suggests that these patches were very small and occurred within areas where there is little evidence of marked erosion. They probably represent local exposed areas on the hardground surface.

Subfacies 2. Sparitic hardgrounds

Hardgrounds with sparite cements are found developed on the oolitic, intraclastic, shell-detrital calcirudites of facies association C. Sparitic hardgrounds are up to 10cm thick and probably extend for distances of up to at least 1km (e.g. between Bearfield and Canal Quarry, Bradford-on-Avon, or between Langton Herring Quarry and Moonfleet Hotel boathouse near Langton Herring). Top surfaces are usually irregular and heavily encrusted. Where not defined by crevices, the lower surfaces are poorly defined, though early fringing cement seldom occurs more than 10cm. below the top surface. The sediment near the hardground surface usually differs from that of the typical calcirudites however. Grain size is smaller and there is considerable development of ooliths and oolitic coatings on shell fragments. There is also an increase in the proportion of quartz sand, all of which forms the nuclei of ooliths, see figure 16. It is interesting to note that oolith formation was probably a necessary prerequisite for hardground formation as calcite cement does not form on quartz grains in Recent submarine hardgrounds (Taylor and Illing, 1969). Early fibrous fringing cement commonly unites the shell fragments. The voids between shell fragments are usually filled either with impure micrite or coarse-grained ferroan calcite.

Spongeliomorpha paradoxica also occurs in the calcirudite hardgrounds but is not found elsewhere in calcirudites in the study area. In fact hardly any traces of bioturbation have been found in unlithified calcirudites.

Intraformational pebbles are commonly found attached to, or immediately overlying, the hardgrounds. These are derived from the lithified layer and usually have a similar attached fauna to that of the hardgrounds. They may show a complex history of derivation from, and

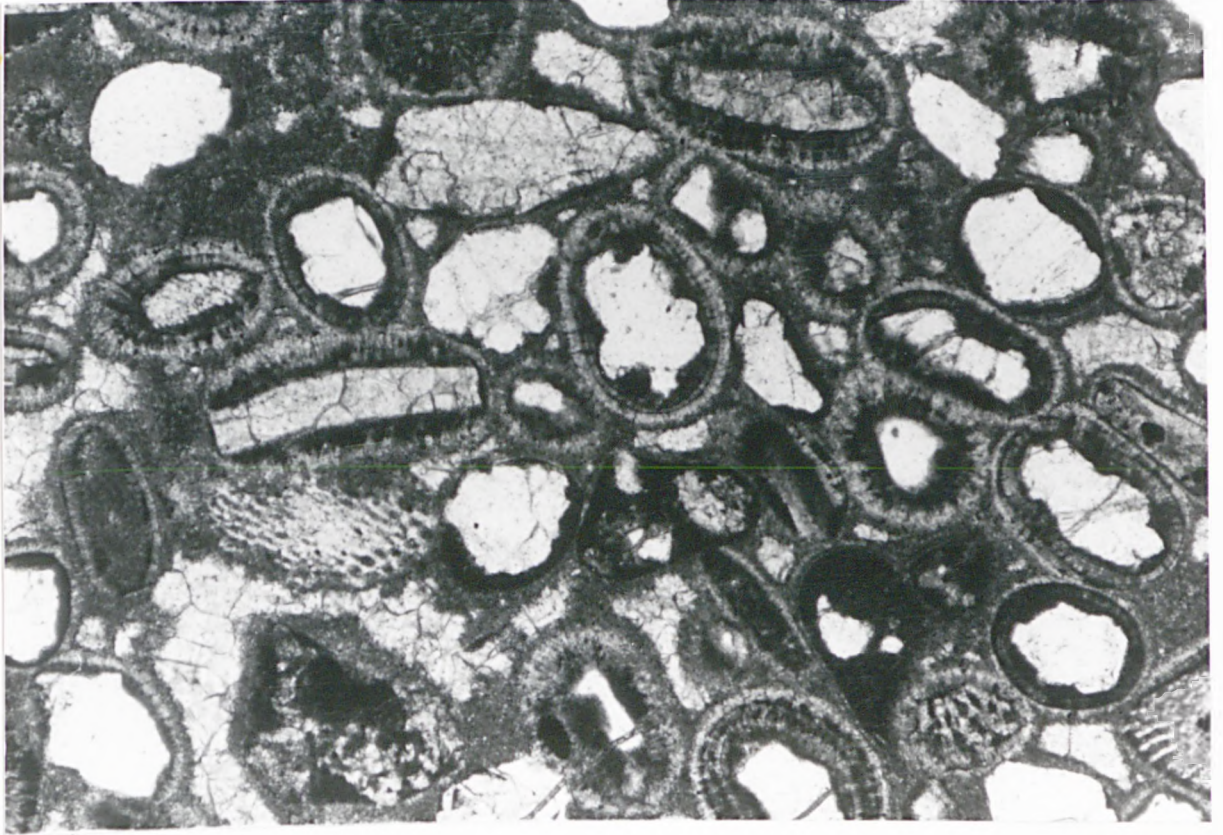


Figure 16. Thin section near surface of Digona Bed hardground, Langton Herring Quarry, showing early cement rims on shell fragments and oololiths with quartz nuclei. x 30

reincorporation into the hardground. Crevices occur beneath the Bradford Clay hardground. These compare closely with those from the micritic hardgrounds.

Discussion

It seems probable that suitable conditions for the production of Spongiomorpha paradoxa in calcirudites may only have existed during the process of synsedimentary lithification. If this is so, burrowing probably took place when the sediment was sufficiently cemented to be stable but not so tightly cemented as to prevent burrow excavation. It is common to find the burrows filled with sandy marl which weathers brown, red or yellow, so it is certainly possible that Spongiomorpha may have been present in other calcirudites and is simply not recognised, due either to burrow collapse or lack of a contrasting sediment fill.

Distribution of hardgrounds in the study area

Hardgrounds are developed in calcirudites beneath the Bradford Clay Fossil Bed, in the Faulkland borehole at a depth of 4.5m, at the base of the Formation at Baggridge Hill, and beneath the Digona Bed in the Weymouth Anticline. This last occurrence has not been previously recorded. A micritic hardground occurs beneath the Boueti Bed and in sediments of facies association A at Herbury Promontory.

Facies 7

FirmgroundsDescription

Whilst all the marls within the Formation show a limited amount of evidence of bioturbation, burrows are not often recognisable in the field as they do not have a clearly contrasting fill. The typical non-branching horizontal burrows seen in the calcareous marl-dominated facies in thin section are easily distinguished from the complex Thalassinoides networks and Rhizocorallium found in the firmgrounds. These normally have a differential fill, usually composed of medium to coarse grained quartz sand and calcarenite. The differential fill shows that they were open to the sediment surface. Frequently, shell debris may be found in the burrows, suggesting that they were open during the period in which the sediment surface was colonised. Burrowing usually only occurs to a depth of approximately 10cm. beneath the firmground surface. Bysally attached faunas are associated with the firmgrounds.

Thickness of firmgrounds is very difficult to define, but burrowing has not been observed to penetrate more than 12cm. below firmground surfaces. The upper surface of firmgrounds as defined by the overlying shell debris is usually broadly horizontal, though burrowing may impart some relief to the surface. The base of firmgrounds is indefinite - they appear to pass gradationally into underlying marl-dominated sediments.

Discussion

The presence of open burrows and of associated bysally attached faunas are the only criteria available for the identification of firmground. However, the fact that such horizons pass laterally into hardgrounds and horizons of lithified pebbles helps support the occurrence of early partial cementation.

Distribution

Firmgrounds occur widely beneath the Boueti Bed in south Dorset, at Redlynch (ST 697333) and also at the Butts, Frome (ST 765472) and in the Marston and Frome boreholes.

Faunas associated with the hardgrounds and firmgrounds

Published work on Bathonian hardgrounds is extensive. The Bradford Clay Fossil Bed and associated fauna were recognised by Smith (1816), who realised that the fauna had developed on the underlying hardground rather than in the Bradford Clay itself. Cunningham (1859), Woodward (1894) and Periam (1956) list the fauna from this horizon at Bradford-on-Avon. Palmer and Fursich (1974) discussed the palaeoecology, demonstrating the polarisation of the boring and encrusting organisms into a hardground surface and a crevice community and their division into stratified feeding levels.

The Digona Bed fauna has been described by Sylvester-Bradley (1958), House (1961) and Torrens (1968).

The Boueti Bed fauna has been described by Woodward (1894), Richardson (1909), Fowler (1957) and Torrens (1969). The stratigraphic significance of the faunas has been discussed by several authors including Woodward (1894), Arkell (1931), Sylvester-Bradley (1958) and Palmer (1974).

Additionally, Elliot (1973) has described the palaeoecology of a "bradfordian" fauna at Sunhill, Glos. which is very similar to some of the faunas from the study area and Palmer (1974) has discussed the palaeoecological significance of "bradfordian" faunas.

There is also a well known and voluminous literature on almost every aspect of hardgrounds. Perhaps the most useful for the interpretation of the significance of the faunas discussed below are papers by Goldring and Kazmierczak (1974), Purser (1969) and

Shinn (1969).

Faunal lists compiled from the sources above for the hardground and firmground horizons in the study area are given below. These are as comprehensive as possible but the detailed taxonomy of brachiopod species is not clear at present. I consider it probable that all the 'species' of Avonothyris are probably part of the same Linnean species and it seems possible that many of the brachiopod genera may have been oversplit. Digonella may be an exception to this however. Brief inspection of collections in the Museum of Practical Geology and the British Museum, as well as my own collection, suggest that either two or three species may be present.

Faunal lists for hardgrounds and firmgrounds

	<u>Boueti</u> <u>Bed</u>	<u>Digona</u> <u>Bed</u>	<u>Bradford</u> <u>Clay</u>	<u>Others</u>
<u>Brachiopoda</u>				
<u>Goniorhynchia boueti</u> (T. Davidson)	X			
<u>Digonella digona</u> (J. Sowerby)	X	X	X	X
<u>Digonella bradfordiensis</u> (Rollier)	X			
<u>Digonella</u> sp. nov.	X			
<u>Avonothyris langtonensis</u> (Walker in Dav.)	X			
<u>Avonothyris bradfordiensis</u> (Walker in Dav.)		X	X	X
<u>Avonothyris obovalis</u> S.S. Buckman	X			
<u>Cryptorhynchia</u> sp.	X			
<u>Acanthothyris bradfordiensis</u> (Walker in Dav.)	X			
<u>Rhynchonelloidella curvivarians</u> (S.S. Buckman)	X	X		X
<u>Epithyris</u> sp.		X	X	X
<u>Epithyris bathonica</u> S.S. Buckman			X	
<u>Rhactorhynchia</u> spp.	X	X	X	
<u>Dictyothyris coarctata</u> (Parkinson)	X	X	X	
<u>Eudesia cardium</u> (Lamarck)	X	X	X	
<u>Moorellina</u> sp.	X			
<u>Kallirhynchia</u> spp.				X
<u>Kutchirhynchia</u> sp.	X			
<u>Kutchithyris</u> sp.	X			
<u>Bryozoa</u>				
<u>Hyporosopora sauvagei</u> (Gregory)		X	No data	
<u>Hyporosopora typica</u> Canu and Bassler	X	X	No data	
<u>Hyporosopora dilatata</u> (d'Orbigny)		X	No data	

Faunal lists for hardgrounds and firmgrounds (cont.)

	Boueti Bed	Digona Bed	Bradford Clay	Others
<u>Bryozoa (cont.)</u>				
<u>Ripisoecia conifera</u> (Lamouroux)		X	No data	
<u>Terebellaria ramosissima</u> (Lamouroux)		X	No data	
<u>Multisparsa lamellosa</u> (Michelin)		X	No data	
<u>Idmonea triquetra</u> (Lamouroux)		X	No data	X
<u>Stomatopora bajocensis</u> (d'Orbigny)	X	X	No data	
<u>Stomatopora dichotomoides</u> (d'Orbigny)	X	X	No data	
<u>Collapora microstoma</u> (Michelin)		X	No data	
Indet. vinculariform cyclostome		X	No data	
<u>Microecia cf. belemnitarum</u> (d'Orbigny)	X		No data	
Indet. bereniciforms		X	No data	
<u>Porifera</u>				
<u>Limnoria</u> sp.	X	X	X	
<u>Peridonella pistilliformis</u> (Lamouroux)	X			
<u>Cliona</u> sp.		X	X	X
<u>Neuropora spinosa</u> (Lamouroux)	X	X	X	X
' <u>Proboscina</u> ' sp.				X
<u>Bivalvia</u>				
<u>Palaeonucula variabilis</u> (J. de C. Sowerby)	X			
<u>Palaeonucula waltoni</u> (Morris and Lycett)	X			X
<u>Dacryomya lacryma</u> (J. de C. Sowerby)		X	X	
<u>Barbatia</u> sp.				X
<u>Cucullaea</u> sp.	X			
<u>Arcomytilus asper</u> (J. Sowerby)	X			
<u>Lithophaga</u> sp.	X	X	X	X

Faunal lists for hardgrounds and firmgrounds (cont.)

<u>Bivalvia</u> (cont.)	<u>Boueti</u> <u>Bed</u>	<u>Digona</u> <u>Bed</u>	<u>Bradford</u> <u>Clay</u>	<u>Others</u>
<u>Modiolus imbricatus</u> (J. Sowerby)	X		X	X
<u>Bakevillia waltoni</u> (Lycett)			X	
<u>Gervillella acuta</u> (J. de C. Sowerby)	X			
<u>Gervillella monotis</u> (J.A. Endes- Deslongchamps)			X	
<u>Isognomon</u> sp.		X		
<u>Oxytoma costatum</u> (Townsend)	X	X	X	X
<u>Meleagrinella</u> cf. <u>lycetti</u> (Rollier)			X	
<u>Entolium</u> cf. <u>corneolum</u> (Young and Bird)			X	
<u>Camptonectes laminatus</u> (J. Sowerby)	X	X	X	X
<u>Camptonectes annulatus</u> (J. Sowerby)	X	X	X	X
<u>Camptonectes rigidus</u> (J. Sowerby)			X	
<u>Camptonectes</u> (<u>Camptochlamys</u>) <u>retiferus</u> (Morris and Lycett)		X	X	
<u>Chlamys</u> (<u>Radulopecten</u>) <u>hemicostata</u> (Morris and Lycett)	X		X	X
<u>Chlamys</u> (<u>Radulopecten</u>) <u>vagans</u> (J. de C. Sowerby)	X	X	X	X
<u>Chlamys</u> (<u>Radulopecten</u>) <u>wollastonensis</u> (Lycett)	X			
<u>Plicatula fistulosa</u> (Morris and Lycett)	X	X	X	
<u>Plicatula</u> sp.	X	X	X	
<u>Placunopsis socialis</u> (Morris and Lycett)	X			
<u>Ctenostreon rugosum</u> (W. Smith)			X	
<u>Plagiostoma subcordiiforme</u> (Greppin)	X	X	X	
<u>Plagiostoma punctatilla</u> (Lycett)			X	
<u>Pseudolimea duplicata</u> (J. de C. Sowerby)		X	X	
<u>Trigonia elongata</u> (J. de C. Sowerby)	X			

Faunal lists for hardgrounds and firmgrounds (cont.)

	<u>Boueti</u> <u>Bed</u>	<u>Digona</u> <u>Bed</u>	<u>Bradford</u> <u>Clay</u>	<u>Others</u>
<u>Bivalvia</u> (cont.)				
' <u>Trigonia</u> ' sp.			X	
<u>Vaugonia moretoni</u> (Morris and Lycett)	X			X
<u>Nicaniella</u> (<u>Trautscholdia</u>) <u>cordata</u> (Trautschold)	X		X	X
<u>Pleuromya uniformis</u>	X			
<u>Gastrochaena</u> sp.	X			
<u>Pholadomya lirata</u> (J. Sowerby)	X			
<u>Pholadomya</u> sp.	X			
<u>Catinula alimena</u> (d'Orbigny)			X	
<u>Catinula ancliffensis</u> (Cox and Arkell)	X	X	X	X
<u>Liostrea wiltonensis</u> (Lycett)	X	X	X	
<u>Praeexogyra hebridica</u> (Forbes)	X	X	X	X
<u>Exogyra crassa</u> (W. Smith)		X	X	
<u>Nanogyra nana</u> (J. Sowerby)		X	X	
<u>Lopha gregaria</u> (J. Sowerby)			X	X
<u>Lopha costata</u> (J. de C. Sowerby)			X	
<u>Echinodermata</u>				
<u>Acrosalenia spinosa</u> (Agassiz)	X		X	X
<u>Cidaris bradfordensis</u> (Wright)	X	X	X	X
<u>Pentacrinus</u> sp.		X	X	
<u>Apiocrinus parkinsoni</u> (Schlotheim)	X	X	X	X
Asterozoan ossicles			X	
<u>Gastropoda</u>				
<u>Pleurotomaria</u> cf. <u>burtonensis</u> Lycett	X			
<u>Turbo burtonensis</u> (Lycett)	X			

Faunal lists for hardgrounds and firmgrounds (cont.)

	<u>Boueti</u> <u>Bed</u>	<u>Digona</u> <u>Bed</u>	<u>Bradford</u> <u>Clay</u>	<u>Others</u>
<u>Gastropoda (cont.)</u>				
<u>Riselloidea biarmata</u> (Münster)	X			
<u>Ataphrus labadyei</u> (d'Archiac)	X			
<u>Pileolus laevis</u> (Morris and Lycett)				X
Indet. Pleurotomariid	X			
Indet. Nerineid		X		
Indet. Micromorphic gastropoda		X	X	
<u>Neridomus costulata</u> (Deshayes)				X
<u>Cephalopoda</u>				
<u>Delecticeras</u> cf. <u>ptychoporum</u> (Neumayr)	X			
<u>Delecticeras</u> sp. juv.	X			
<u>Cadomites</u> or <u>Polyplectites</u> sp. indet.			X	
<u>Clydoniceras hollandi</u> (S.S. Buckman)		X	X	
<u>Clydoniceras</u> sp. juv.		X		
Indet. sulcate Bélemnite	X			
<u>Phoronida</u>				
<u>Talpina ramosa</u> von Hagenow	X	X	X	X
<u>'Vermes'</u>				
<u>Trypanites</u> sp.	X	X	X	
<u>Annelida</u>				
<u>Sarcinella socialis</u> (Goldfuss)	X			
<u>Serpula</u> (<u>Cycloserpula</u>) spp.	X	X	X	
<u>Serpula</u> (<u>Dorsoserpula</u>) spp.	X	X	X	X
<u>Serpula</u> (<u>Tetraserpula</u>) sp.	X	X	X	X
<u>Serpula intestinalis</u> (Phillips)	X			

Faunal lists for hardgrounds and firmgrounds (cont.)

	<u>Boueti</u> <u>Bed</u>	<u>Digona</u> <u>Bed</u>	<u>Bradford</u> <u>Clay</u>	<u>Others</u>
<u>Annelida (cont.)</u>				
<u>Serpula sulcata</u> (J. de C. Sowerby)	X			
<u>Serpula limax</u> (Goldfuss)	X			
<u>Cirrepeda</u>				
Acrothoracican borings			X	
<u>Crustacea</u>				
<u>Vertebrata</u>				
<u>Hybodus</u> sp.				
Fish vertebrae and scales				X -
<u>Corals</u>				
<u>Montlivaltia slatteri</u> Tomes	X			
<u>Montlivaltia trochoides</u> Edwards and Haime	X			
<u>Isastrea limitata</u> (Lamouroux)	X	X		
<u>Thamnasteria</u> sp.		X		
<u>Anabacia</u> sp.			X	

Palaeoautecology of the Faunas

Brachiopods

With the exception of the cementing Thecidean Moorellina, which has only been found attached to crevices beneath the hardgrounds, all the brachiopods were pedically attached low level suspension feeders. No evidence of pedicle attachment scars has been found on any shell debris or upon hardground surfaces. Nests of brachiopods in fine sediments have not been found.

Sponges

Five sponge taxa are present amongst the faunas. Of these, 'Cliona' is represented only by borings of the ichnogenus Entobia. The borings are up to 2.5mm. wide. They are only rarely found on rock surfaces and have not been recorded from loose shell debris. In the Digona Bed they show a marked preferential occurrence in the upturned edges of 'Liostrea' attached to the hardground. A similar occurrence, in attached Plicatula, is recorded from the Bradford Clay hardground at Bradford-on-Avon (Fursich and Palmer, 1975).

The calcisponge Limnoria shows a marked preference for the underside of hardgrounds. It is rare in the Boueti Bed and has not been recorded from outside the hardgrounds. Peronella and Proboscina usually occur on shell debris but may also occur on rock surfaces. Peronella has been found encrusting Goniorhynchia boueti near the anterior commissure, probably to take advantage of the feeding currents. Neuropora spinosa is common to the Boueti Bed and Digona Bed, where it occurs on brachiopod tests.

Serpulids

Seven species of 'Serpula' are present in the hardground and firmgrounds. The taxonomy of the subgenera Serpula (Cycloserpula),

Serpula (Dorsoserpula) and Serpula (Tetraserpula) follows Palmer and Fursich (1974). All the species they identify are present. Serpula (Cycloserpula) sp.2 is very common on lower surfaces and considerably larger though rarer on upper surfaces. Serpula (Dorsoserpula) sp.2 is confined to upper surfaces of hardgrounds but, along with S. (Cycloserpula) sp.2, is common on shell debris, frequently occurring on both sides of disarticulated bivalves. This suggests that such shell debris may have been flipped over by waves or currents to provide either sheltered or exposed habitats on both sides at different times. Serpula intestinalis (Phillips), S. sulcata (J. de C. Sowerby) and S. limax (Goldfuss) have all been recorded in the past from the Boueti Bed, e.g. Wilson et al (1958) but in this account no attempt has been made to separate them; all serpulids are referred the genera given above. The colonial serpulid Sarcinella socialis is apparently confined to the Boueti Bed.

Ectoprocts

These can be divided into crustose low-level suspension feeders and branching arborescent high level suspension feeders. The latter have not been found attached to loose shell debris. The growth forms of the various taxa are shown below:

Arborescent

Terebellaria ramosissima

Ripisoecia conifera

Collapora microstoma

indet. vinculariform cyclostome

Crustose

Hyporosopora spp.

Stomatopora spp.

Plagoecia sp.

Mesenteripora sp.

Microecia cf. belemnitarum

Idmonea cf. triquetra

Multisparsa lamellosa

Mesenteripora sp. and Stomatopora dichotoma have only been recorded from the lower surface of the Bradford Clay hardground (Palmer and Fursich, 1974).

Echinoderms

Apiocrinus is found attached to the upper surfaces of hardgrounds only. Occasionally joint holdfasts secreted by two individuals may occur. Loose Apiocrinus ossicles are common in shell debris above firmgrounds however.

Pentacrinus holdfasts are never found and thus it may have been free living (Palmer, 1974). Asterozoan ossicles are only found dissociated. The echinoids Acrosalenia spinosa and Cidaris bradfordensis were probably vagile algal browsers.

Corals

Isastrea and Thamnasteria were attached colonial species. The solitary corals of the Anabacia type, found only in the Bradford Clay fauna were probably free living in the adult stage (Palmer and Fursich, 1974). Montlivaltia may also have been free living as individuals are often found with a bent corallum which has resulted from attempts to grow vertically in response to slow subsidence.

Cirripedes

Acrothoracican borings have been recorded from crinoid ossicles in the Bradford Clay hardground only.

Bivalves

The palaeoautecology of the Bivalves from all facies associations is summarised in table 1. All living representatives of any given superfamily fall within one, or rarely, two feeding groups (Stanley, 1968). The functional morphology of each genus is a useful guide

to its ecological niche, and using a combination of both these factors may give a useful guide to the mode of life of the organism and the environment in which it lived.

In most Recent and fossil Bivalve assemblages, three feeding groups may be recognised; infaunal suspension feeders, epifaunal suspension feeders and deposit feeders. The latter are all infaunal. Epifaunal suspension feeders feed by filtering suspended particles from the water which is drawn over the ctenidia. Infaunal suspension feeders can be divided into infaunal non-siphonate suspension feeders, infaunal siphonate suspension feeders and infaunal mucous-tube feeders (Stanley, 1968). Infaunal non-siphonate suspension feeders move around near the sediment-water interface and draw in water through a thin layer of sediment. Infaunal siphonate suspension feeders extract food from water drawn in through siphons and may be mobile or sedentary. Infaunal mucus-tube feeders obtain a water current through a tube lined with mucus running to the sediment-water interface. This is constructed by the foot (Allen, 1958).

Further observations on the palaeoecology of certain bivalve genera is given below:

Oxytoma Palmer and Fursich (1974) suggest that Oxytoma may have been bysally attached to hardgrounds or shell debris. It also occurs in the Oxford Clay, where it is often clustered on a mud substrate. Because of the extremely soft substrate Duff (1978, p.16) suggested a pendent mode of life.

Nicaniella (Trautscholdia) High inflation, strong ribbing and thick shell suggest a sluggish, shallow burrowing mode of life (Duff, 1978).

Protocardia It is likely that Protocardia lived very close to the sediment-water interface, the radial ribbing perhaps helping to

camouflage the shell when covered with a thin veneer of sediment (Duff, 1978). It has not been found in this orientation or in fine-grained sediment in the present study.

Camptonectes This genus was probably strongly bysally attached throughout life.

Palaeonucula Nuculids live immediately beneath the sediment surface. They feed using palps with which they probe the sediment and extract organic matter from it.

Quenstedtia Tellins feed by means of an inhalent siphon with which they draw in organic matter at the sediment-water interface. They live on the right valve with the commissure horizontal. However, some Tellins may use both deposit-feeding and suspension mechanisms (Pohlo, 1969).

Pteroperna probably adopted an adpressed byssate mode of life rather than 'free-swinging' as it is markedly inequilateral with one flat (adpressed) valve and one convex valve.

Placunopsis may have been cemented to the substrate (Stenzel, 1971) but no unambiguous attachment areas, and no right valves have been recorded in this study. Palmer (1974) also could not find Placunopsis attachment areas and suggested that it may have been cementing or bysally attached through an occluded bysall notch in a largely aragonitic right valve, which would have lower preservation potential than the left valve.

Range of substrate types and faunas developed in the facies association

In the following section descriptions of the facies associations at various localities are given in order to give an idea of the range of substrate types and faunas at the various localities and horizons. A supplementary list of localities and sections in the facies association is given in Appendix 2. All faunal lists are compiled from personal collections unless otherwise stated.

The Boueti Bed at Watton Cliff, West Bay

The Boueti Bed at this locality overlies the grey marls of the upper Fuller's Earth Formation. At the base of the Boueti Bed are very large Thalassinoides networks in which average burrow diameter is approximately 4cm. These burrows do not penetrate very deeply into the underlying Fuller's Earth and are not immediately apparent in the cliff section. They are best seen when large blocks of the bed are removed from the section. In size and appearance they closely resemble the Thalassinoides at the junction of the Forest Marble and lower Cornbrash Formations at Shipton-on-Cherwell Quarry, Oxfordshire.

The thickness of the Bed varies between approximately 25cm and 40cm. The basal 20 - 30cm is composed largely of a grain supported coquina. The shell fragments are lightly cemented at grain junctions and the matrix of the sediment is characteristically rather heterogeneous. Patches of impure marly grey micrite are present but the majority of the matrix is composed of grey marl. The heterogeneity of the matrix is probably due to differential cementation.

Inside articulated and closed brachiopod shells, pellets occur composed of calcareous marl or marly limestone. These are very small; maximum diameter is less than 1mm, and must have entered through

the pedicle foramen. The pellets often grade into apparently structureless marl, suggesting that they may have been fairly soft at the time of deposition and even in a protected environment may have compacted and lost their original texture. This raises the possibility that a large proportion of the matrix may once have been pelleted and the texture largely obliterated by compaction and other diagenetic effects. The small size and apparent softness suggests that they may not have been true faecal pellets but might have been produced by suspension feeders ingesting clay size sediment during the feeding process and expelling it as pseudofaeces. This process occurs in suspension feeding bivalves, in particular in the oysters (Stenzel, 1971, p.N1001) and implies the presence of turbidity due to the suspension of fine sediment. Exactly similar pellets occur in the bed at Herbury Promontory.

The shell debris shows some evidence of post mortem transport. The majority, but not all, of the bivalve debris is disarticulated and some of it is broken with the broken edges slightly rounded, whether by leaching or by abrasion is unknown. However, encrusting organisms on shell debris are seldom worn and ^{though} the brachiopods are among the most resistant of bivalves to disarticulation, transport for distances of about 5km. completely destroys them (Middlemiss, 1962). Post-mortem transport is difficult to assess in a geological context, but more and more studies have shown that the effects of shell debris transport, even in high energy environments, rarely produce highly distorted assemblages of shells differing considerably from life assemblages (Johnson, 1972; Cadée, 1968). The breakup of shell debris, together with the accentuation provided by diagenetic processes, suggests that it is unlikely that identifiable fossils have been transported sufficiently to affect assemblage composition greatly.

Rarely, infaunal bivalves occur in the coarse shell debris, sometimes still articulated. Whether these have been exhumed from soft sediment by bioturbation or by physical erosion is uncertain, but the commonest genus, Pholadomya, has never been found in life position.

The top 5 - 10cm of the bed is dominated by the small oyster Catinula ancliffensis. This frequently encrusts shell debris or forms small nests of individuals encrusting one another. This oyster frequently exhibits xenomorphic growth, especially when attached to Rhynchonellid fragments, caused by passive moulding while the shell is growing at the valve margins. When the oyster is very small it must grow closely adpressed to its substratum to avoid exposure to shell-crushing predators. As the left valve follows the contours of the substratum and the oyster is very flat, the right valve must leave no gap at the commissure and so must follow the shape of the left valve and hence the object to which it is attached. The phenomenon is clearly not heritable (Stenzel, 1971, p.N1022) and its frequency in this species is simply a reflection of its small size.

In the top few centimetres of the bed, the marl matrix may support the shell debris and some specimens of C. ancliffensis appear to be reclining. Patches of unfossiliferous marl are present.

The fauna recorded from the locality is listed below:

- Brachiopoda: Goniorhynchia boueti (Dav.)
 Avonothyris langtonensis (S.S. Buckman)
 Digonella bradfordiensis (Rollier)
 Digonella sp.
 Dictyothyris coarctata (Parkinson)
- Bivalvia: Arcomytilus asper (J. Sowerby)
 Gervillella acuta (J. de C. Sowerby)

- Camptonectes laminatus (J. Sowerby)
Chlamys (Radulopecten) hemicostata (Morris and Lycett)
Chlamys (Radulopecten) vagans (J. de C. Sowerby)
Trigonia elongata var. lata J. de C. Sowerby
Trigonia elongata var. gracilis J. de C. Sowerby
Vaugonia moretoni (Morris and Lycett)
Nicaniella (Trautscholdia) cordata (Trautschold)
Pholadomya sp.
Catinula ancliffensis Cox and Arkell
Praeexogyra hebridica (Forbes)
- Gastropoda: Pleurotomaria burtonensis Lycett
Turbo burtonensis Lycett
- Coelenterata: Montlivaltia sp.
- Echinodermata: Apiocrinus parkinsoni
'Cidaris' sp.
- Porifera: Peridonella sp.
- 'Vermes': Serpula (Dorsoserpula) sp. 2*
Serpula (Cycloserpula) sp. 2*
Serpula (Tetraserpula) sp.
Serpula intestinalis (Phillips)
Serpula sulcata (J. de C. Sowerby)

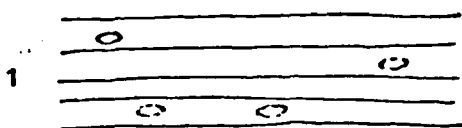
* of Palmer and Fursich (1974)

A certain amount of ecological succession can be inferred at this locality. There is considerable diversity of burrowing taxa including 5 bivalve species and Thalassinoides organisms, though the latter have not been found and are only represented by their burrows.

It seems probable that these may have preceded the epifaunal, bysally attached and encrusting elements of the fauna as the majority would not be able to survive in either coarse shell debris or in small patches of marl. The exception to this might have been Nicaniella (Trautscholdia) cordata which, because of its small size could have led an infaunal life in small marl patches. This strongly suggests mixing of successive communities to form a time-averaged assemblage, fig 17.

The transition to the C. ancliffensis dominated marl at the top must represent a response to a change in environment, though this small oyster is present throughout the bed. The increase in the proportion of matrix to shell debris suggests that an increase in the rate of sedimentation was responsible. This would have an adverse effect on a suspension-feeding community as it would lead to an increased uptake of sediment during feeding. This would lead, in turn, to energy loss as food is sorted from sediment and eventually to swamping of the organisms or perhaps to the loss of attachment sites for larvae. It is possible that conditions may have been more suitable for C. ancliffensis because of its small size, the characteristic that most obviously distinguishes it from the other oysters. Oysters in general have an efficient self-cleansing mechanism which enables them to live in sediment laden waters (Stenzel, 1971). Small size could have been an advantage in allowing a short life cycle. Most oysters reach sexual maturity very early; Ostrea equestris from the east coast of the Americas may mature in as little as 22 days (Stenzel, 1971), when the oyster is thus very small. It seems possible that Catinula, a very small-sized genus, may have been adapted to conditions which would have been marginal to other oysters which increase a great deal in size after reaching maturity. One advantage of large size in oysters is an increase in fecundity.

Fig.17 Diagrammatic illustration of firmground evolution



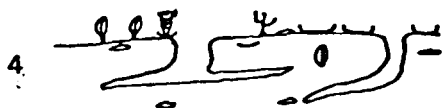
Finegrained soupy marl deposited - only poorly defined Planolites visible



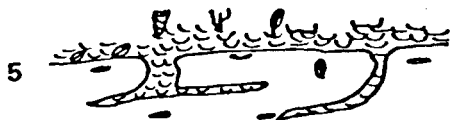
Marl consolidates - infaunal bivalves colonise sediment



Decapod crustaceans produce Thalassinoides - minor erosion may take place



Epifaunal community becomes established, either directly on firm mud or on exhumed shell fragments



Burrows become filled as thick shell layer builds up. Bioturbation or storm action mixes shell debris



Increase in sedimentation rate - Catinula becomes dominant as remaining fauna is choked by sediment



Catinula choked by sediment as soupy marl deposition resumes

Another is presumably that larger oysters are less liable to predation. It is tempting to speculate that Catinula ancliffensis may have been adapted to an environment in which a short life cycle was an advantage to avoid choking in sediment, and in which great fecundity was not particularly advantageous and where predation of small individuals was not great. If competition was reduced by the absence of other organisms, great fecundity would not be an advantage and predation would not be a great problem to the species.

The fact that several centimetres of marls dominated by C. ancliffensis occur at the top of the Boueti Bed at almost every locality as far north as the southern slopes of the Mendips, suggests that the conditions leading to the replacement of the diverse Boueti Bed community and eventual demise of the fauna were widespread and not particularly sudden.

At Watton Cliff, the Boueti Bed is succeeded by some 14m. of calcareous marls and sand- and silt-streaked marls. Calcareous marls and marls with silt laminae which were probably deposited in waters with very limited turbulence predominate towards the base of the succession. Pyritic nodules are present approximately 40cm. above the bed. Sedimentological evidence suggests therefore, that a return to quiet water sedimentation and possibly low-oxygen conditions may have been the cause of the disappearance of the suspension-feeding community.

The conditions in which the suspension feeders thrived were probably shallow water with some bottom turbulence. Some evidence for bottom turbulence is provided by the serpulid morphology. All the serpulids found in the Boueti Bed appear to have the anterior portion of their tubes cemented firmly to the substrate. Some Recent serpulid genera, such as Pomatoceras, raise the anterior

portion of the tube off the surface in deep quiet water conditions, presumably in order to avoid intake of mud with feeding currents. This habit certainly occurred in the Jurassic; encrusted ammonites in the Kimmeridgian of Staffin Bay, Skye show serpulids exhibiting this mode of life. However, it does not occur in the Boueti Bed. Turbulence, or at least unidirectional currents, are unlikely to have been excessive, as streams of serpulids which develop in these conditions are not found.

Shallow water at this locality, as at many others, is indicated by the presence of algal browsing organisms such as 'Cidaris' sp. This indicates the presence of a layer of endolithic algae which is characteristic of shallow water.

The presence of a fauna dominated by suspension feeding organisms is also indicative of current action. This provides a continuously changing supply of water and thus a continuous supply of suspended food.

The exact means by which the assemblage became established remains uncertain. Certain epifaunal taxa may simply have become attached to the firm, burrowed marl substrate, or alternatively to shell fragments derived either from adjacent areas where a community was already established or from infaunal bivalves exhumed by bioturbation or erosion. Following the establishment of a layer of shell debris, plenty of attachment sites would be present for the support of the epifaunal community

The Boueti Bed at Birt's Hill, Halstock, and Honeycombe Wood, Sherborne

At Birt's Hill the Boueti Bed outcrops at an altitude of approximately 380' O.D. In 1977 a very fine temporary exposure was present at Chanter's Guile (ST 514083) during regrading of the stream banks.

The section is recorded below:

<u>Catinula ancliffensis</u> - dominated marls	c 20cm
Boueti Bed continuous with above	30 - 35cm
micritic hardground	2 - 14cm
Thin cementstones and unfossiliferous cream marls	2m seen

At Honeycombe Wood, near Sherborne, the Boueti Bed is exposed in a small stream section near the top of the wood (ST 637141) (Torrens, 1969). The Thornford pipe-trench also passed through the Boueti Bed elsewhere in Honeycombe Wood (Fowler, 1957) where I have only been able to make small collections. Additional material was kindly lent by H.S. Torrens.

At all these localities, the Boueti Bed overlies a hardground. At Honeycombe Wood the hardground is only 2 - 4cm thick and is composed of sand-streaked cream micrite, the laminae of which are broken by bioturbation. The upper surface of the hardground shows evidence of considerable bioerosion with large holes produced by overlapping Lithophaga crypts lowering the level of the surface about 1 - 1.5cm in places. The upper surface is extensively bored by Lithophaga sp. and encrusted by large L. wiltonensis. Beneath the lithified layer, cavities must have been present, as its lower surface is also heavily bored by Lithophaga sp. and encrusted by Cycloserpula sp., Liostrea wiltonensis and Hyporosopora typica. The oysters show considerable evidence of erosion even in the cavities and are extensively bored, suggesting a period of erosion before final burial. The crevices and cavities are similar to those described from Jurassic hardgrounds by Purser (1969), Fursich (1971) and Palmer and Fursich (1969) and from Recent hardgrounds in the Persian Gulf by Shinn (1969). They originated probably from enlargement

of pre-existing burrows or unlithified patches in the hardground by biological and mechanical erosion.

At Birt's Hill, the hardground is developed in sediments of very similar lithology to those at Honeycombe Wood. Here the hardground may be up to 14cm. thick and has a knobbly, irregular upper surface which is broken up into pebbles in some places. Crevices beneath the hardground are also present at this locality. The attached crevice fauna is:

Cycloserpula sp.

Praeexogyra hebridica

Limnoria sp.

Plicatula sp. 2

Hyporosopora spp.

The hardground is bored from both above and below by Lithophaga and from above by Gastrochaena and Trypanites and Entobia. The upper surface of the hardground has an extensive encrusting fauna listed below:

Plicatula fistulosa

Liostrea wiltonensis

Praeexogyra hebridica

Nanogyra nana

Lopha gregarea

Serpula (Dorsoserpula) sp.

Serpula (Cycloserpula) sp.

Serpula (Tetraserpula) sp.

Microecia cf. belemnitarum

Apiocrinus parkinsoni

Sarcinella socialis

Hyporosopora spp.

Within the lithified layer, ecological succession can be shown to have occurred. The principal factor controlling the faunas of the hardground itself was almost certainly the degree of consolidation or cementation of the substrate. Most benthonic organisms have a limited range of tolerance to the degree of sediment consolidation and, to some extent, consolidation can therefore be estimated from the tolerance ranges of modern taxa (Goldring and Kazmierczak, 1974).

Probably the first community to inhabit the sediment was entirely a burrowing one; some very indistinct burrows may be seen in specimens from Birt's Hill. Rhoads (1970) distinguished between burrows made in thixotropic sediment and those produced in plastic sediment. Burrows made in thixotropic sediment have very indistinct outlines and those in plastic sediment have sharp outlines. Whilst these distinctions are not easy to make in practice, it is certainly possible to see a series of progressively better defined burrow outlines in the hardground. The most distinct burrows are those assigned to the ichnogenus Spongeliomorpha paradoxa (Woodward). These must have been made in plastic sediment as they were dwelling burrows and lack any obvious means of support. Other well defined burrows attributed to Trypanites are present. The Trypanites organism is cited by Goldring and Kazmierczak (1974) as an example of an animal which can produce both borings and burrows.

The poorly defined bioturbation structures are cross-cut by Spongeliomorpha and Trypanites, which are in turn cross-cut by Lithophaga and 'Gastrochaena' crypts. This clearly demonstrates the age relationships of the episodes of burrowing and boring and confirms the succession in relation to the degree of consolidation of the sediment.

No shelly macrofauna is present within the lithified layer

which might represent a pre-hardground or firmground community.

An encrusting fauna is present on the walls of Spongiomorpha networks, proving that they must have remained open after lithification. It is composed of Cycloserpula sp., Catinula sp. and crustose bryozoans.

A full list of the fauna found associated with the hardground is given below. The list for Honeycombe Wood is compiled from Fowler (1957) and Torrens (1969).

HONEYCOMBE WOOD

Brachiopoda:

Goniorhynchia boueti

Avonothyris langtonensis

Avonothyris obovalis

Dictothyris coarctata

Cryptorhynchia sp.

Acanthothyris bradfordensis

Digonella digona

Digonella bradfordensis

Digonella sp.

Echinodermata:

Acrosalenia spinosa

Apiocrinus sp.

Gastropoda:

Riselloidea biarmata

Ataphrus labadyei

Pleurotomaria sp.

'Vermes':

Serpula intestinalis

Serpula sulcata

Cephalopoda:

Delecticeras sp.

Antherozoa:

Montlivaltia slatteri

Isastrea limitata

Bivalvia:

Cucullaea sp. indet

Arcomytilus asper

Modiolus imbricatus

Girvillella acuta

HONEYCOMBE WOOD (cont.)

Bivalvia (cont.):

Camptonectes rigidusChlamys (Radulopecten) vagansTrigonia elongataNicaniella (Trautscholdia) cordataPleuromya uniformisCatinula ancliffensisLiostrea wiltonensisPraeexogyra hebridicaLopha gregarea

BIRT'S HILL, HALSTOCK

Brachiopoda:

Goniorhynchia bouetiAvonothyris langtonensisDigonella bradfordensisDigonella sp.Dictyothyris coarctataMoorellina sp.

Bryozoa:

Hyporosopora sp.Hyporosopora typicaMicroecia cf. belemnitarum

Bivalvia:

Girvillella acutaCamptonectes rigidusChlamys (Radulopecten) vagansPlicatula fistulosaPlicatula sp.Catinula ancliffensisLiostrea wiltonensisPraeexogyra hebridica

'Vermes':

Serpula (Dorsoserpula) sp.Serpula (Cycloserpula) sp.Serpula (Tetraserpula) sp.Sarcinella socialis

Echinodermata:

Apiocrinus parkinsoni

At Honeycombe Wood, infaunal bivalves are present showing that soft substrates were present as well as lithified ones. Modiolus imbricatus may have been semi-infaunal and, if this was the case, it would

require a soft substrate. The fact that these bivalves are found above the hardground shows that mixing of the faunas has occurred.

The fauna in Boueti Bed localities where hardgrounds are developed differs in composition from those where marl and shell debris are the main substrate types, the difference being chiefly in the number of encrusting taxa present. Some taxa seem to show a preference for very stable (rock) substrates rather than loose shell debris. These include Lithophaga sp., Gastrochaena sp., Trypanites, Moorellina sp., Liostrea wiltonensis and Plicatula fistulosa. Palmer and Fursich (1974) note the preference of Plicatula sp. for rock or other Plicatula as substrates. Lithophaga and Gastrochaena are known to bore biogenic material on the hardground but only if it is attached to the substratum.

As in all Boueti Bed localities, with the exception of Redlynch Park, the top part of the Boueti Bed is dominated by Catinula ancliffensis. (Fig.18).

The Boueti Bed at Redlynch

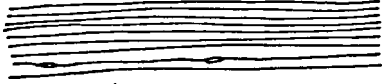
A temporary exposure on both sides of a track opposite the entrance to Home Farm, Redlynch Park (ST 697333) shows the section below:

FOREST MARBLE:


Oolitic calcirudite	13cm
Calcareous marl	1cm
Oolitic calcarenite	1cm
Ferruginous marl	1cm
Oolitic calcarenite and calcirudite	13cm
Grey, silty marl	2cm
Iron-rich clay with pyrite nodules	1cm
Grey marly limestone and fossiliferous silty marl	9cm

Fig.18 Diagrammatic illustration of hardground evolution

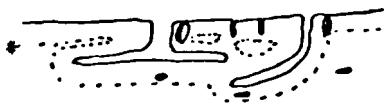
- 1



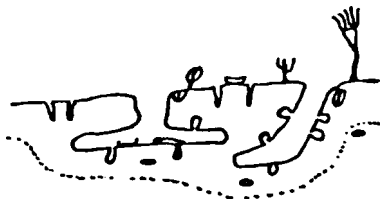
Indistinct burrows disturb laminations in soft sediment
- 2



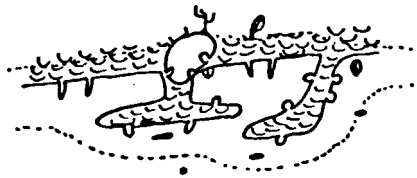
Substrate consolidates during depositional hiatus. Infaunal bivalves may colonise sediment
- 3



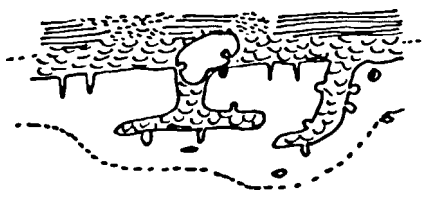
Open burrows produced by worms and decapod crustaceans. Lithification begins in marginal zone limited by exchange of pore waters
- 4



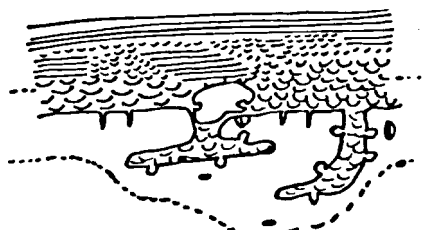
Boring and encrusting communities thrive - polarisation of upper surface and crevice communities
- 5



Physical erosion and bioerosion occur, loose pebbles may be re-incorporated into the hardground as cementation continues, shell debris layer develops
- 6



Increase in sedimentation rate - Catinula becomes dominant as remaining fauna is choked
- 7



Annelids again become dominant faunal element as soupy marl deposition resumes

Rounded, bored marly limestone
pebbles (0-3cm.) in fossiliferous
marly limestone and cream silty
marl 8cm

UPPER FULLER'S EARTH

Light grey sandy calcareous marl 2.2m seen

This section forms the basal part of the graphic log shown in figure 19.

The base of the Boueti Bed is not as clearly defined as in the southern localities as it is intensely bioturbated. Thalassinoides may be seen penetrating the top 2 - 5cm of the Fuller's Earth marls. The burrows are considerably smaller than those at Watton Cliff; average diameter being approximately 0.8cm. The texture of the bed is a matrix-supported fossiliferous marly limestone with intraformational, bored, encrusted micritic pebbles occurring in a single horizon 8cm above the base. The pebbles are up to 12cm in maximum diameter and show evidence of having been rolled. They are bored by Lithophaga sp. on all sides and are encrusted by Cyclo-serpula sp., Dorsoserpula sp. and Praeexogyra hebridica. These pebbles do not show any signs of a late diagenetic origin and are therefore not considered to be exhumed concretions in the sense of Kennedy and Klinger (1972). They show traces of early burrows similar to those found at Birt's Hill, Halstock and are thought to represent an arrested stage of hardground formation. It is probable that they represent early lithified sediment from around which the surrounding soft sediment has been eroded. Following rolling, boring and encrustation they were buried by fine sediment which was not lithified at the time of burial.

The fauna is listed below:

Brachiopoda:

Goniorhynchia boueti

Avonothyris langtonensis

SECTION OPPOSITE HOME FARM, REDLYNCH
(ST 697333)

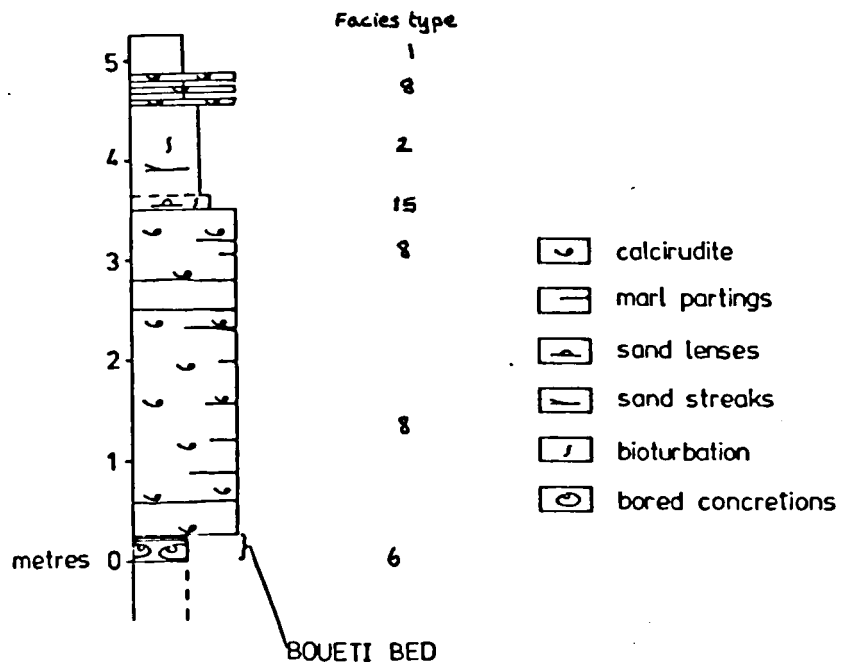


Figure 19.

Digonella digonaDigonella bradfordensisDigonella sp.Rhynchonelloidella curvivarans

Bivalvia:

Palaeonucula waltoniBarbatia sp.Arcomytilus asperLithophaga sp.Modiolus imbricatusGirvillella monotisCamptonectes laminatusChlamys (Radulopecten) vagansC. (R.) hemicostataC. (R.) wollastonensisPlagiostoma punctatillataNicaniella (Trautscholdia) cordataCatinula ancliffensisPraeexogyra hebridicaMontlivaltia slatteri

Gastropoda:

Turbo burtonensis'Pleurotomaria' sp.Actaeonid gastropods

Vermes:

Serpula (Tetraserpula) sp.Serpula (Cycloserpula) sp.Serpula (Dorsoserpula) sp.

Porifera:

Clionid borings

Catinula ancliffensis is rare at this locality. It does not dominate the upper part of the bed as at other localities reflecting a difference in the depositional environment. This and the absence of encrusting calcisponges and bryozoans may reflect the rarity of suitable attachment points. However, epifaunal, bysally attached bivalves dominate the fauna.

Other aspects of the fauna and depositional environment of the Boueti Bed

Other localities:

Certain faunal elements found in the Boueti Bed do not occur at the localities described above. These are given below:

Eudesia cardium

Rhactorhynchia sp.

Neuropora spinosa

Hyporospira sauvagei

Stomatopora dichotomoides

S. bajocensis

Encrusting calcareous algae

Eudesia cardium and Rhactorhynchia occur near Seat Hill, Batcombe.

The other species are all recorded from Herbury Promontory, Langton Herring.

Encrusting calcareous algae are found on bivalve debris, particularly pectens, at Herbury Promontory only.

There is a noticeable thinning of the bed northwards. G. boueti becomes rarer as the Mendips are approached and has not been found north of the Mendips. This may well be because its range is limited rather than because the bed itself is absent.

In general the Boueti Bed at Watton Cliff is typical of all localities on the Dorset Coast. Exposure is poor inland until Birt's Hill is reached, which appears typical of the Sherborne area. North of Wincanton, localities are extremely sparse and no locality can really be regarded as typical.

It is clear that the Boueti Bed represents a condensed series of somewhat mixed and time averaged communities. Succession can be clearly shown at most localities and appears to be related chiefly to changes in substrate hardness and to sedimentation rate.

The Digona Bed

This bed was probably discovered by F.H.A. Engleheart (c. 1925) at Langton Herring Quarry (SY 608822). A fauna recorded by Arkell (1947) from Herbury Promontory also probably refers to this bed. It was

mapped by House (1961) who records the fauna. Sylvester-Bradley (1958) added to Engleheart's faunal list and correlated it with the Bradford Clay Fossil Bed at Bradford-on-Avon, rejecting the correlation of the Bradford Clay and Boueti Bed proposed by Woodward (1894). He thus became the first author to recognise that bradfordian faunas were developed at different times rather than all being deposited during the time represented by the Bradford Clay Fossil Bed. The fauna from Langton Herring Quarry is listed by Torrens (1968).

The Digona Bed is limited in its outcrop to a small area around Langton Herring and Abbotsbury. It is developed on the top of the main calcirudite body in the area. It was named by Sylvester-Bradley probably because, at that time, true D. digona was not thought to occur in the Boueti Bed.

The Digona Bed at Langton Herring Quarry

The following section was exposed by excavation of the north face of the quarry:

Grey marls	2cm	} Digona Bed
Cream micrite	15cm	
Blue-grey marls	8cm	
Oolitic, burrowed, bored and encrusted calcirudite	35cm. (base unseen) Top 15cm cross-bedded	

The underlying hardground is composed largely of shell debris most of which is coated by oolitic laminae. This is rather unusual for the Forest Marble calcirudites and may reflect a period of slow sedimentation in turbulent waters, conditions which are known to be suitable for hardground formation (Dravis, 1979). Significant quantities of angular and subangular quartz sand are present, mostly forming the nuclei of ooliths. The calcirudite is grain supported and shows two generations of cement. There is an early radial sparry

fringe on ooids and shell fragments and a void-filling secondary cement of ferroan calcite. Unfilled voids become more common below the upper surface of the lithified layer.

The hardground is burrowed by Spongeliomorpha paradoxa which have a differential yellow clay fill. The upper surface of the hardground is bored by Lithophaga sp. and encrusted by several layers of Praeexogyra hebridica, Liostrea wiltonensis, Exogyra crassa and Nanogyra nana. Small 'Exogyras' are here referred to as N. nana but may simply be juvenile E. crassa. Most of these oysters are represented by their lower valves only. Many of the encrusters are penetrated by Talpina ramosa, Entobia and Lithophaga. No crevices have been found beneath the hardground.

The fauna is listed below:

Brachiopoda:

Digonella digona

Avonothyris bradfordensis

Rhactorhynchia sp.

Dictyothyris coarctata

Rhynchonelloidella curvivarans

Bivalvia:

Palaeonucula waltoni

Dacryomya lacryma

Lithophaga sp.

Oxytoma costatum

Chlamys (Radulopecten) hemicostata

Chlamys (Radulopecten) vagans

Plicatula fistulosa

Plagiostoma subcardiiforme

Pseudolimea duplicata

'Trigonia' sp.

Gastrochaena sp.

Liostrea wiltonensis

Praeexogyra hebridica

Exogyra crassa

Nanogyra nana

Lopha gregarea

Bryozoa:

Multisparsa lamellosa

Ripisoecia conifera

Terebellaria ramosissima

Collapora microstoma

Idmonea triquetraHyporosopora typicaHyporosopora dilatataHyporosopora sauvageiStomatopora bajocensisStomatopora dichotomoides

Indet. vinculariform cyclostome

Echinodermata:

Apiocrinus parkinsoni'Cidaris' sp.

Gastropoda:

Indet. Nerineid gastropod

Indet. micromorphic gastropod

'Vermes':

Tetraserpula sp.Cycloserpula sp.

The diverse bryozoan fauna includes elements such as Terebellaria ramosissima and Multisparsa lamellosa which are essentially part of the Normandy Bathonian bryozoan fauna rather than the British (P.D. Taylor, pers. comm. 1979).

The shallow burrowing taxa Dacryomya lacryma, Palaeonucula waltoni and 'Trigonia' sp. are not derived from the underlying calcirudites but from the overlying micrites and marls, showing that the succession associated with the hardgrounds is primarily dependent on substrate type rather than other ecological factors.

This locality is the only one in the Digona Bed where Digonella digona is present in any numbers. The individuals are somewhat smaller than those at Bradford-on-Avon but are undoubtedly the same species.

At the Moonfleet Hotel boathouse, Langton Herring (SY 616806) a section disturbed by rotational slip is present. Isolated elements of the Digona Bed fauna and large blocks of the hardground may be found immediately west of the boathouse. The hardground is similar in grain size and lithology to that at Langton Herring Quarry but associated with it are large rounded disc-shaped cobbles up to 18cm.

in length. Following initial lithification and encrustation these pebbles were derived from the hardground, rounded and then reencrusted on both flatter sides. It seems probable that the hardground layer was not fully lithified when the pebbles were derived and rounded as very high energy conditions would be required if this were the case. Most of the non-cementing taxa associated with the Digona Bed are absent at this locality and may have been removed by local high energy conditions responsible for the rounding of the hardground pebbles.

The majority of the diverse ectoproct faunas are found encrusting the large pebbles where they form the only element of the fauna, apart from cementing bivalves which are extremely worn and probably lived attached to the hardground before derivation of the pebbles.

The fauna from the locality is recorded below:

Brachiopoda:

Digonella digona

Avonothyris sp.

Rhactorhynchia spp.

Eudesia cardium

Dictyothyris coarctata

Bivalvia:

Lithophaga sp.

Oxytoma costatum

Camptonectes (Camptochlamys) retiferus

Plicatula fistulosa

Plagiostoma subcardiiforme

Liostrongia wiltonensis

Catinula ancliffensis

Praeexogyra hebridica

Exogyra crassa

Nanogyra nana

Cephalopoda:

Clydoniceras hollandi (M)

'Vermes':

Dorsoserpula sp.

Cycloserpula sp.

Bryozoa:

Ripisoecia coniferaTerebellaria ramosissimaCollapora microstomaMultisparsa lamellosaIdmonea triquetraHyporosopora sauvageiHyporosopora typicaStomatopora bajocensisThe Digona Bed at Herbury Promontory (SY 6125 8085)

The bed is exposed by a small fault in the middle of the south side of the Promontory but is normally obscured by slip off the low cliff.

The section is:

Light grey biomicrite	10cm. seen
Cross-bedded oolitic calcirudite	18cm. seen

The fauna is recorded below:

Isastrea limitataThamnasteria sp."Epithyris" sp.Apiocrinus parkinsoniTerebellaria ramosissimaHyporosopora sp.Lithophaga sp.Isognomon sp.Chlamys (Radulopecten) hemicostataPlagiostoma subcardiiforme'Gastrochaena' sp.Liostrea wiltonensisPraeexogyra hebridicaDorsoserpula sp.Tetraserpula sp.

The corals are found adhering to the hardground surface and have truncated tops encrusted by Praeexogyra hebridica and are bored by 'Gastrochaena' sp. The presence of these corals along with an ammonite and brachiopods confirms the stenohalinity of the depositional environment.

The biomicrite above the hardground contains an infauna including Isognomon sp. and Thalassinoides. It is not clear why the conditions in these lime muds were more suitable for infaunal organisms than in

the marly clays that succeeded the Boueti Bed, but better water circulation and a more favourable relationship between the organic matter content and sediment grain size may have been important factors.

Bradfordian faunas of uncertain stratigraphic position

East side of Herbury Promontory, Langton Herring, Dorset (SY 614802)

The section here is assigned to the lower Forest Marble on lithological grounds as faulting and poor exposure obscure its relationship to surrounding beds. It is recorded below:

Top 1.	Calcareous marl with silt streaks	80cm
↑ 2.	Encrusted, bored, sandy, silty micrite pebbles	0-14cm.
3.	Calcareous marl with sand streaks	138cm,
4.	Rippled fine sandstone with silt drape	3-6cm
5.	Calcareous marl with sand streaks	28cm seen

Bed 4 outcrops along the foreshore of the Fleet and forms a marker bed from which the fauna associated with bed 2 can be located.

The pebbles of bed 2 are extremely knobbly and unrounded and are not closely packed. There are large patches of unlithified calcareous marl and shell fragments between them. The pebbles show evidence of early burrowing and contain infaunas which must have developed prior to lithification. These factors, plus the extensive boring and encrusting faunas associated with the pebbles, suggest that they originated in situ by a process of synsedimentary submarine lithification. Analogous lumps of lithified sediment occur seaward of continuous hard layers beneath the lagoons of the Persian Gulf at the present time. (Taylor and Illing, 1969). Growth of hardgrounds appears to have taken place by coalescence of such lumps (Bathurst, 1971, p.372). In the Persian Gulf, such lumps may be exhumed and

micritised by algae and their undersurfaces bored. Thalassinoides networks have been observed deflected or curved round the concretionary lumps (cf. Bromley, 1967b) in this locality as well as in the Boueti Bed hardground at Birt's Hill. This proves that burrowing took place in soft or firm sediment during the lithification process, as well as before it.

Trace fossils of the ichnogenus Entobia, probably produced by Clionid sponges are particularly common, both in the upturned edges of cemented Bivalves and in the upper and lower surfaces of the lithified sediment itself.

The fauna of bed 4 is listed below:

<u>Oxytoma costatum</u>	<u>Nicaniella (Trautscholdia) cordata</u>
<u>Neridomus costatulata</u> (Deshayes)	<u>Girvillella</u> sp.
<u>Pseudolimea duplicata</u>	<u>Praeexogyra hebridica</u>
<u>Apiocrinus parkinsoni</u>	<u>Tetraserpula</u> sp.
<u>Nucula (Palaeonucula) waltoni</u>	<u>Dorsoserpula</u> sp. 2
<u>Trigonia</u> sp.	<u>Chlamys (Radulopecten) vagans</u>
<u>Plicatula fistulosa</u>	<u>Trigonia (Vaugonia) moretoni</u>
<u>Catinula ancliffensis</u>	<u>Lithophaga</u> sp.
<u>Pentacrinus</u> sp.	<u>Camptonectes retiferus</u>
<u>Cycloserpula</u> sp. 2	<u>Kallirhynchia</u> sp.

N. (P.) waltoni, A. (T.) cordata, Trigonia sp. and T. (V.) moretoni are all found in the calcareous marls between the lumps as well as incorporated in the early lithified sediment. These are thought to be the infauna present at the locality and to represent the infaunal community during the process of hardground formation in the calcareous marl substrate.

Railway Cutting at East Cranmore, Somerset (ST 695434)

At this locality a band of encrusted calcareous concretions is

present approximately 9.2 metres below the base of the middle Forest Marble calcirudites (fig. 14). The concretions are composed of pyritic calcareous marl containing approximately 5% of angular to subangular medium quartz sand. The sediment was intensely bioturbated before lithification and the quartz is consequently unevenly distributed, preferentially accumulating in burrows. Bivalve crypts occurring round the margins of the concretions do not truncate

grains and have irregular outlines, suggesting that they may have been made in firm, rather than fully lithified, sediment.

The fauna associated with this horizon is:

<u>Idmonea triquerta</u>	<u>'Proboscina'</u> sp.
<u>Stomatopora bajocensis</u>	<u>Hyporosopora sauvagei</u>
<u>Hyporosopora typica</u>	<u>'Cidaris'</u> sp.
<u>Apiocrinus</u> sp.	Fish scales and vertebrae
<u>Chlamys (Radulopecten) vagans</u>	<u>Pholadomya lirata</u>
<u>Praeexogyra hebridica</u>	<u>Oxytoma costatum</u>
<u>Exogyra crassa</u>	<u>Rhynchonelloidella</u> sp.
<u>Avonothyris</u> sp.	<u>"Epithyris"</u> sp.
<u>Digonella digona</u>	<u>Rhactorhynchia</u> sp.

The paucity of bivalves in this fauna probably reflects collection failure. The fauna is no longer exposed and isolated ex situ concretions form the only source of material.

The Butts, Frome (ST 765472)

A stream section on the north side of Whitemill Lane in the lower Forest Marble yielded the following fauna:

<u>Digonella digona</u>	<u>Kallirhynchia</u> sp.
<u>Rhynchonelloidella curvivarans</u>	<u>Avonothyris</u> sp.
<u>Chlamys (Radulopecten) vagans</u>	<u>Chlamys (Radulopecten) hemicostata</u>
<u>Catinula ancliffensis</u>	<u>Oxytoma costatum</u>

Praeexogyra hebridicaDorsoserpula sp.Cycloserpula sp.Tetraserpula sp.

No evidence of synsedimentary lithification is present at this locality. The fauna is the most obviously autochthonous assemblage found in the study area. It contains entire articulated specimens of bivalves as well as brachiopods. The low faunal diversity may thus reflect the lack of mixing of faunas from a patchy community in which both hard and soft substrates were present. Although burrows are visible in the sediments, exposure is so poor that a well-developed firmground was not recorded.

The exact stratigraphic position of this fauna is unknown as no marker horizon is available to which it can be tied. It occurs at the base of the scarp of the middle Forest Marble calcirudites and, if the section is not faulted, at approximately the same horizon as the Boueti Bed at Seat Hill, Batcombe.

The Bradford Clay hardground and associated fauna

This hardground and its attached encrusting and boring fauna have been comprehensively studied by Palmer and Fursich (1974) at two localities in Bradford-on-Avon; Canal Quarry (ST 826600) and Springfield (ST 831609). Neither these nor any other localities at this horizon were exposed between 1976 and 1979 but digging at Canal Quarry revealed various elements of the fauna described by Palmer and Fursich and yielded one small hardground fragment.

Whilst recognising the polarisation of the encrusting and boring faunas into hardground and crevice community, Palmer and Fursich also record a more subtle succession amongst these organisms. On crevice roofs Plicatula shows a marked preference for rock substrates and was the first organism to colonise them, followed by fauna dominated by serpulids, ectoprocts and Moorellina (Palmer and Fursich, 1974, p.518). Their recognition of stratification of feeding levels amongst the hardground communities is widely applicable in the facies association.

Discussion of faunas and their succession

The faunas of the facies association include several stenotopic groups; corals, echinoderms and brachiopods as well as rare cephalopods. No species indicative of non-marine deposition have been recorded. The faunas therefore appear to have been open marine in character though probably developing in quite shallow, agitated conditions. Although the fauna at any one point appears to be diverse, up to 31 species being recorded at any one locality, this may simply reflect the diversity of niches in the hardgrounds and firmgrounds and the time-averaged association of species from separate successive communities. The time averaged nature of the assemblages is more noticeable in the Boueti Bed as early burrows of veriform and crustacean origin are recognisable in the micritic hardgrounds but not the sparitic ones.

It is interesting to note that no such faunas are found associated with sediments of facies association D. This suggests that the depositional environment of Association D was unsuitable for development of these faunas and may not have been open marine in character. Open marine faunas are present only towards the base of the Formation. The highest hardground or firmground fauna above the base of the Formation is the Digona Bed which occurs approximately 19m above the Boueti Bed in a succession about 30m thick in the Weymouth Anticline (Sylvester-Bradley, 1958). It is overlain by up to 1.6m of grey impure marly micrite.

Comparison of the faunas developed on the upper and lower surfaces of the Bradford Clay, Boueti Bed and Digona Bed hardgrounds

Table 2 shows that the upper surface community shares 10 species of boring and encrusting taxa, excluding bryozoans, where it seems possible that the identifications of Palmer and Fursich (1974) may not be identical to those of P.D. Taylor, who kindly identified them for this study. Those found exclusively on the upper surfaces are Liostrea wiltonensis, Plicatula fistulosa, Apiocrinus parkinsoni and Clionid borings. Exclusive to bottom surfaces are; Limnoria sp.,

Plicatula sp. 2 (of Palmer and Fursich, 1974) and Moorellina. To the upper surface community can probably be added the echinoids, bysally attached bivalves and brachiopods. Recent asterozoans often prefer the undersurfaces of such habitats (Palmer and Fursich, 1974) and thus may have formed part of the cryptic community.

Thus it seems that there are at least two communities that can be recognised in several localities and a series of successive soft substrate and epifaunal communities that can be inferred to have existed. The burrowing taxa Nicaniella (Trautscholdia) cordata, 'Trigonia' spp. and Thalassinoides have been found associated in micritic limestones of association C and may thus have formed part of a recurring community as they are also recognised in the Boueti Bed of Watton Cliff.

The idealised succession in the Boueti Bed and in the firmgrounds appears to be similar, but differs slightly from that in the sparitic hardgrounds.

In the former, the soft mud colonised by burrowing worms appears to have consolidated, allowing the development of Thalassinoides networks and the presence of burrowing bivalves, as in the Boueti Bed at Watton Cliff. The next stage in development appears to have been the development of an epifaunal, bivalve and brachiopod dominated community upon which encrusting organisms lived. In some cases this stage was preceded by patchy synsedimentary submarine lithification of the sea floor to produce hardground surface and cryptic communities. In the case of the Boueti Bed this seems to have been followed by a final phase of colonisation, largely by Catinula ancliffensis, perhaps in response to increased sedimentation.

In the sparitic hardgrounds, e.g. the Digona Bed and Bradford Clay Fossil Bed, lithification may have been proceeding at the same

time as crustacean burrows were being excavated. Almost synchronously these burrows may have become enlarged to produce a polarised hard-ground and crevice community. There is no evidence of a Catinula dominated community following after the hardground and crevice faunas.

Discussion

The cryptic community developed in these hardground crevices can be compared with Recent cryptic communities growing in reefs in Jamaica, the Pacific Ocean and the Red Sea. These cryptic habitats can be divided into overhangs or interiors of caves and crevices and the undersides of foliaceous corals. In the darker caves and crevices thecidean brachiopod/coralline sponge communities dominate. bivalves are not common but cheilostome ectoprocts and encrusting algae are abundant (Jackson, Goreau and Hartman, 1971). The ectoproct, thecidean, coralline sponge, serpulid and bivalve dominated community found on the undersurfaces of the hardgrounds bears many resemblances to this fauna, though serpulids and bivalves are fairly common and coralline algae are not. It is pointed out by Palmer and Fursich (1974) that Plicatula sp. is a pioneer species on the lower surfaces of the hardgrounds and is succeeded by a fauna dominated by serpulids, ectoprocts and Moorellina.

It has been suggested that cryptic reef habitats first became important in the Middle Jurassic when cavernous coral reefs first became important, probably in response to more rapid growth induced by dependence on zooanthellae and also the large non-encrusting foliaceous growth form apparently unique to scleractinian corals (Jackson, Goreau and Hartman, 1971). This new niche may have been first exploited by the brachiopods and coralline sponges that are ancestral to those observed in this habitat today.

In this connection it is interesting to note that although shaded crevices occur in the Liassic hardground represented by the Coinstone on the Dorset coast they do not appear to be encrusted by bryozoans or coralline sponges but by serpulids alone (Hallam, 1969b).

Stratigraphic implications of the hardgrounds, firmgrounds and associated faunas

An understanding of the sedimentological and palaeoecological significance of the facies association throws light on two of the major stratigraphic problems of the Forest Marble Formation. Firstly, can the Digona Bed be shown to be the time equivalent of the Bradford Clay Fossil Bed at Bradford-on-Avon? Secondly, can the Great Oolite (sensu Green and Donovan, 1969), which occurs between the Fuller's Earth and Forest Marble from Baggridge Hill northwards, be shown to be chronostratigraphically or lithostratigraphically equivalent to any part of the Forest Marble south of Baggridge?

The terms Great Oolite and Forest Marble are used below in the sense of Green and Donovan (1969), i.e. the Upper Rags are excluded from the Forest Marble.

The first question is raised by the correlation of the Digona Bed and Bradford Clay Fossil Bed by Sylvester-Bradley (1958). Implicit in his correlation was the recognition that the bradfordian faunas of southern England were not all synchronously deposited as he changed the correlation, made by Woodward (1894), of the Boueti Bed with the Bradford Clay and recognised that the Digona Bed overlies the Boueti Bed in the Weymouth Anticline.

Sylvester-Bradley based his correlation on the occurrence of abundant true D. digona in both horizons and suggested that this made the Digona Bed faunas more similar than those of the Bradford Clay than the Boueti Bed. As D. digona is now known to be widespread

in the autochthonous fossiliferous horizons of the Forest Marble, including the Boueti Bed, the faunal evidence for his correlation is unconvincing.

It is clear from field mapping that the Digona Bed does not occur outside the Weymouth Anticline. Details of the outcrop within the Weymouth Anticline are given by House (1961). Sedimentological evidence suggests that the calcirudites upon which it formed may have been deposited as a submarine shell body of positive relief, probably a tidal shoal, (see p.140).

This may also have been the case with the Bradford Clay Fossil Bed, which rests on at least 2m. of cross-bedded biosparites (Palmer and Fursich, 1974, p.508) though these are nowhere exposed at present.

If this was the case, the position of these hardgrounds on local topographic highs suggests that submarine lithification may have occurred purely locally when turbulence was at exactly the right level to prevent the deposition of fine sediment from suspension and yet not result in grain movement on the shoal top. Such conditions would probably only rarely occur and be confined to the individual shoal tops. As the cross-bedding in the calcirudite, of which the Digona Bed hardground is formed, must have originated from grain movement, the hardground probably indicates at least a temporary reduction in the energy of the environment.

Other examples of submarine lithification of tops of calcirudite bodies occur rarely outside the study area in Oxfordshire (Palmer, 1974).

The shell bodies of facies association C are thought to be broadly lensoid in shape and to occur at slightly different stratigraphic levels in relation to marker horizons such as the Boueti Bed and the base of the Cornbrash. Therefore the likelihood of

the Digona Bed and Bradford Clay Fossil Bed being of exactly the same age is low. The markedly similar faunas of the two beds are almost certainly due to the very closely comparable environments in which they developed. This is supported by faunal evidence which suggests that the Formation as a whole in the study area is a shallowing upwards sequence and may be diachronous, see pp.185-188.

The problem of the chronostratigraphic relationships of the Forest Marble, Fuller's Earth and Great Oolite is unfortunately not so easily assessed as it involves making positive chronostratigraphical correlations in the virtual absence of ammonites or other time significant macrofaunas. The best available alternative is to use lithological evidence which, combined with a careful interpretation of the depositional environment, can be very useful in elucidating the time relationship of the three units. The most promising facies for this work are without doubt the hardgrounds and firmgrounds, as they are quite widespread and may sometimes be traced for short distances in the field.

Soviet geologists have pioneered the use of hardgrounds and firmgrounds for stratigraphic correlation, for example in the Middle Ordovician of Estonia (Mannil, 1966). It has more recently been suggested (T.J. Palmer personal communication 1978; Penn and Wyatt, 1979) that hardgrounds and firmgrounds may be of use in correlation within the Great Oolite Group, over short distances at least. However, some caution needs to be exercised in making these correlations. Rose (1970) has shown that the presence of hardgrounds in the Edwards Formation (Lower Cretaceous) of Texas do not represent a single period of non-deposition but the scattered and repeated occurrence of similar depositional environments, and suggests that a previous correlation based on a misinterpretation of the hardgrounds as representing a

single period of subaerial exposure is wrong. There is no doubt that hardgrounds and firmgrounds also occur frequently in the Forest Marble Formation, and if they can be traced at outcrop in the field, there is no reason why they should not be used as a lithostratigraphic marker horizon.

If hardgrounds (and laterally equivalent firmgrounds) are to be used for chronostratigraphic purposes it is vital to decide whether or not they are diachronous. Studies of Recent hardgrounds in the Persian Gulf show that they are without doubt diachronous, and that the diachroneity appears to be related to sedimentary transgression. Cores taken from the deepest part of the Gulf penetrate several metres of basinal calcareous marls before encountering a layer of lithified calcarenite which shows signs of having been deposited in shallow marine Recent hardground nearer shore. The diachroneity of the submarine lithification may be proved by ^{14}C dating and is apparently related to the Flandrian transgression. Today the lithification process is most active at a depth of approximately 20 metres, where stable, coarse sediment is found and slow sedimentation rates favour the process (Purser, 1969). Thus the implication is that a zone of submarine lithification has advanced progressively shorewards as sea level has risen over the last 10,000 years.

Perhaps the best example of a hardground which passes laterally into a firmground in this study is provided by the Boueti Bed, which passes southwards from a patchy hardground at Redlynch in Somerset to a firmground on the Dorset coast. Recent evidence that hardgrounds pass laterally into discontinuous lithified lumps and eventually into soft sediment in shallow water comes from the Persian Gulf (Taylor and Illing, 1969). In deep water, the degree of lithification may vary from the scarcely detectable to the completely indurated (Fischer

and Garrison, 1967)). In the case of the Boueti Bed, variation in the degree of lithification of the substratum is probably due to variations in clay content (see above p.56).

In many ways it is possible to draw remarkably close parallels between the Boueti Bed and its overlying sediments and the Recent hardgrounds and overlying marls in the Persian Gulf. On the Dorset coast there is a considerable thicker development of calcareous marls above the Boueti Bed than there is in the area immediately south of the Mendips. For example, at Watton Cliff, approximately 14m of marl-dominated sediments occur between the main calcirudites and the Boueti Bed, whereas at Redlynch Park the calcirudites immediately overlie it. Whilst it is admitted that calcirudites may occur throughout the lower 20m of Forest Marble sections in the study area, the Boueti Bed does occur nearer to the base of the scarp formed by the main development of the calcirudites in the north than the south of the area. Thus the thickness of marls above the Boueti Bed before the incoming of 'high energy' calcirudites increases in the same direction as the thicknesses indicated by the Bathonian isopachytes proposed by Martin (1967), i.e. basinwards. It seems possible therefore that the Boueti Bed could be somewhat diachronous and related to post-Upper Fuller's Earth basin filling. The striking analogy with the hardgrounds of the Persian Gulf suggests that this diachroneity could represent as little as 10,000 years.

However, the Boueti Bed has usually been regarded as a synchronously deposited horizon, and there is no doubt that widespread synchronously deposited burrowed horizons do occur. These have been documented over vast areas of Kansas and Colorado in the Upper Cretaceous Greenhorn Limestone (Hattin, 1971). Here benthonites are present to show the time relationship of the various strata. In the Greenhorn Limestone the burrowed horizons are 'chalky' marls and the commonest trace fossils are Planolites, Chondrites, Tigillites,

Thalassinoides and mineral-filled and pellet-filled burrows.

Though the evidence for any diachroneity of the Boueti Bed is rather inconclusive, its widespread nature certainly seems to differentiate it from the Digona Bed and Bradford Clay Fossil Bed hardgrounds, which probably formed in response to very localised, shallower water, shoal-top conditions.

The fact that the Boueti Bed is so widespread, and thus probably formed because of some change in depositional environment of a regional nature, suggests that it might be possible to trace it northwards over the Mendips and thus determine its stratigraphical relationships with other bradfordian faunas in the vicinity of Baggridge Hill, where the Great Oolite appears between the Forest Marble and Fuller's Earth.

The most northerly locality at which G. boueti has been recorded is Harwood Farm, West Cranmore (ST 67954180) (Green and Donovan, 1969). It is very noticeable that G. boueti becomes considerably rarer in the Boueti Bed as the southern slopes of the Mendips are approached and it seems possible that the Boueti Bed may extend northwards from this locality but simply lack the diagnostic species. North/south variations in the range of other brachiopod species in the bed may also be observed. For example Digonella digona does not occur south of Sherborne, and Digonella sp. does not extend north of Redlynch. If this is the case, it might prove possible to trace at outcrop a bradfordian fauna which passes laterally into the Boueti Bed at West Cranmore. Unfortunately there are several severe problems to be overcome if this is to be done. Firstly, the basal Forest Marble is faulted out against the Fuller's Earth less than 2km north of West Cranmore, obliterating the junction in the crucial area. Secondly, several bradfordian faunas have been recorded north of the

Mendips at approximately the same level as the Boueti Bed.

At Baggridge Hill (see fig.4) a fauna containing Digonella spp., Eudesia cardium and Dictyothyris coarctata has been identified at the base of the Upper Rags. This is the lowest occurrence of a bradfordian fauna in the area. It passes laterally into a mudstone sequence with a thin bed containing a bradfordian fauna marking the base. This shelly bed can be identified in the Rudge and Faulkland boreholes, but does not persist into the Frome and Marston boreholes (Penn and Wyatt, 1979), see fig. 58.

In Baggridge No.1 borehole the base of the Forest Marble is marked by the top of a hard, porcellanous, bored hardground with an associated bradfordian fauna. Though this hardground is well documented (Green and Donovan, 1969; Penn and Wyatt, 1979) I have been unable to obtain any samples in the field. This hardground is not present in Baggridge No.2 but recurs in Baggridge No.3. In both No.1 and No. 3 boreholes it clearly occurs at the top of the Upper Rags carbonates.

Approximately 1.7km. to the south of Baggridge No.3 two well-developed bradfordian faunas occur beneath the middle Forest Marble limestones. They occur at depths of between 21.7 and 22.7 metres and 33.9 metres respectively. If, as suggested (Penn and Wyatt, 1979) the lower of these two faunas is laterally equivalent to the base of the Upper Rags, then the upper one may possibly be correlated with the hardground at the base of the Forest Marble at Baggridge. However, bearing in mind the presence of locally developed bradfordian faunas in the south of the area, this correlation cannot be said to be proved. Neither of these two faunas have been identified at outcrop.

At Frome (Gibbet Hill borehole, ST 76324769) bradfordian faunas

are also present. Diverse faunas occur at 17.8m., 19.5m. and 22.5m. The uppermost of these faunas which overlies a burrowed horizon has been taken as the base of the Forest Marble (Penn and Wyatt, 1979), and the lowest as the base of the Upper Rags. One of these faunas is present in a stream section at The Butts, Frome (ST 765472), though which one is unknown.

At Marston (Little Sharpshaw Farm, ST 75214528) the uppermost fauna, overlying a burrowed horizon, is identifiable. The fauna recorded here is quite diverse and can confidently be correlated with that in the Frome borehole. It occurs 7.1m. below the base of the Forest Marble calcirudites.

No outcrop evidence is available to connect this faunal horizon with the Boueti Bed, known only 4km. to the southwest, except that it occurs at approximately the same level relative to the Forest Marble calcirudites. This is an extremely tenuous connection as the calcirudites are known to vary slightly in their vertical relationship to the Boueti Bed.

In summary, though the relationship of the Boueti Bed to the base of the Forest Marble where it overlies the Great Oolite is still uncertain, the possibility that extremely detailed mapping could prove a continuous faunal horizon connecting the two is undoubtedly present. However, even if this was done, the problem of whether this horizon could be shown to be synchronously deposited would still remain.

Finally, if the Boueti Bed could be shown to die out at the south slopes of the Mendip Hills, it raises the possibility that the environment of deposition in which it was developed was confined to the area south of the Mendips and hence that it may have been limited by the Mendip Swell.

CHAPTER FOUR FACIES ASSOCIATION C

Calcirudites facies association

Introduction

This facies association is dominantly composed of shell-detrital calcirudites, though micrites are also included. The calcirudites are extremely complex sediments whose description and interpretation are hampered by relatively poor exposure. There is a good coastal section at Watton Cliff, West Bay which, although not completely inaccessible as suggested by Arkell (1931), is only accessible at three points. Inland there are many small quarries once worked for lime, road metal and building stone. Most of these have not been in use for at least thirty years and many have been completely levelled. Those that are still open commonly have badly weathered surfaces upon which the sedimentary structures have been almost obliterated. Consequently a better understanding of some facies has been gained by visiting localities outside the study area where exposure is better.

The calcirudites normally form a pronounced scarp in the centre of the succession in the study area. This is particularly well seen at North Hill, between Bridport and Burton Bradstock, and between Frome and Marston Bigot. However, the calcirudites are probably not a continuous sheet of shell-rich material. In some sections, e.g. Baggridge No.1 borehole, two or more major calcirudite bodies may occur, whereas in others, e.g. West Hill, Sherborne, calcirudites are only very poorly developed. Borehole logs show that the calcirudite bodies occur at slightly different levels relative to the Boueti Bed and the base of the Cornbrash. Consequently it is probable that the calcirudites occur as a number of separate lensoid shell bodies, though these may be stacked or imbricated against

each other to form a more or less continuous scarp.

Calcirudites are not confined to the central part of the succession, they also occur as thin beds up to 25cm thick interbedded in the sediments of facies associations A and D.

As far as can be determined from the limited exposure available, the calcirudite sequences can be broadly divided into four types:

1. Channel sequences.
2. Isolated single beds less than 40cm thick.
3. Sequences composed largely of flat-bedded and cross-bedded sheets and lenses of calcirudite. These may be up to 10 m thick.
4. Giant cross-bedded sets up to 8m thick.

These sequences are composed of a number of separate facies described below. Following the facies descriptions are descriptions and interpretations of the sequences as a whole.

Facies 8. Flat bedded and cross-bedded sheets and lenses of calcirudite

This facies is by far the commonest and most widely distributed in the Formation, forming at least part of the calcirudite succession at almost all localities. The thickest development is at Charlton Horethorne (ST 669240), where a succession 8m thick is present. Other localities at which it is well displayed are Baggridge Hill (ST 754569), Frome Railway Cutting (ST 784486) and Henstridge Quarry (ST 711195).

Description.

In general, the facies is composed of sheets and lenses varying in thickness between 1cm. and 1m. These are commonly laterally continuous for several tens of metres, though lateral continuity is extremely variable. Sheets may be up to at least 200m. long, yet many lenses persist for only a metre or so and are bounded by erosion surfaces. The isolated, flat-bedded sheets of calcirudite which occur occasionally in marl-dominated sediments appear to be the most continuous laterally and are always less than 40cm thick.

The sheets and lenses commonly amalgamate and are often separated by marl drapes that swell and pinch considerably. The marl drapes may be partially ripped up and incorporated into an overlying calcirudite sheet. Sometimes they are draped over erosion surfaces but more often they preserve a smooth hummocky surface on the tops of calcirudite sheets with a relief of up to 15cm. The top surfaces of sheets and lenses have not been observed to preserve dune morphologies. The hummocky surfaces are very similar to those described by Hamblin and Walker (1979) from the Passage Beds of the Fernie formation of Alberta.

The internal organisation of the sheets and lenses is often difficult to determine. In flat-bedded horizons the shell debris

is usually dominantly convex upwards when seen on bedding surfaces but no preferred orientation of shell fragments in the horizontal plane is normally observed.

Occasionally individual beds may be picked out by grain size differences in the shell debris, as at the west end of Watton Cliff, where a lens 2.5m thick at the base of a shell body can be divided in this way into beds 10 to 30cm thick,

In thin section many apparently massive beds can be shown to contain centimetre-scale alternating laminations of oolites and shell debris. However, the majority of flat-bedded sheets and lenses have no apparent internal partings.

Weathering has a deceptive effect on bed thickness. Towards the tops of quarries weathering splits the sediment parallel to the bedding giving a false impression of a thin bedding rather than more massive outcrop.

Cross-bedding is frequently present in the facies. It is normally of extremely variable angle, even within a single set. Low angle cross stratification at angles between 10° and 20° is most characteristic, and frequently passes laterally into either higher angle or horizontal stratification. The details of cross-bedding are difficult to see in the calcirudite as they are usually only picked out by the presence of elongate or disc shaped marl intraclasts aligned diagonally across a bed. Occasionally isolated marl drapes may be found aligned diagonally across apparently flat-bedded beds. In such cases it is usually impossible to decide whether the drape marks an erosional or a depositional feature. Cross-bedding surfaces are often irregular or wavy rather than smooth. Within a single set cross-bedding varies greatly in apparent direction of dip, suggesting that the bedforms responsible were, in general

terms, lobate rather than straight crested.

Small, shallow, parallel scours have been observed on bedding planes within the facies at Watton Cliff only (fig.20).

Lithologically, the facies is composed of coarse and fine shell debris, intraclasts and various subsidiary components including oololiths and lignite, set in a predominantly sparite cement. The shell debris is composed dominantly of bivalve and echinoderm debris with lesser quantities of gastropod, brachiopod, ectoproct, serpulid, foram, ostracod and vertebrate remains. The shell fragments are mostly bored by sponges, bryozoans, ? phoronids and algae. Shell debris composition was estimated from point counts of thin sections from five localities (Table 3).

Table 3. Point counts of identifiable shell fragments from facies 8.

	% Bivalve	% Echinoderm	% Gastropod	% Bryozoan	% Brachiopod	% Serpulid	% Foram	% Vertebrate	% Ostracod	n=
Herbury Promontory	59.6	29.5	8.2	3.3	5.5	1.9	-	-	-	538
Abbot's Hill	49.4	24.9	11.3	3.5	6.9	2.3	1.2	1.2	0.6	316
Burton Mere	51.3	22.4	14.3	3.1	6.3	2.5	-	-	-	425
Charlton Horethorne	44.7	35.4	10.5	3.3	1.9	5.4	0.5	-	-	558
Bothenhampton	49.2	14.6	8.8	23.3	1.7	2.2	-	-	-	361
Mean %	50.8	25.4	10.6	7.3	4.5	2.9	0.3	0.2	0.1	

Point interval: 0.5mm.

Intraclasts of four types occur in the facies. Bored pebbles of unfossiliferous grey micrite up to 15cm in maximum diameter occur rarely and tend to be concentrated along certain bedding planes. Unfortunately, concentrations of such pebbles have only

been identified ex situ and their sequential position in the calcirudite bodies is unknown. Two specimens of bored, matrix-supported, sparsely oolitic micrite pebbles have been recorded from Watton Cliff (Freeman, 1976). Watton Cliff is the locality which contains the greatest number of lithified pebbles but they do occur at other localities and were first recorded by Sorby (1879), who was also the first to record the frequent dissolution of aragonitic shell debris in the calcirudites.

All the remaining intraclasts are composed of marl which shows little sign of lithification. The most common marl intraclasts are disc shaped and rounded or subrounded. They average 1 - 3cm. in diameter and 3 - 5mm in thickness, but very large clasts up to 20cm long and 3cm thick have been recorded. The lithology of these intraclasts is the same as that of the marl partings and drapes in the facies, though they are frequently weathered yellow or brown. The clay mineralogy of the intraclasts has not been studied. Large, approximately spherical marl intraclasts occur less commonly. These may have originated as armoured mud balls similar to those recorded from tidal channels in the Florida Keys (Jindrich, 1969). However, they are invariably set in a matrix of shell debris so it is extremely difficult to tell whether they originally contained a skin of shell fragments.

The majority of ooliths found in the facies are spherical. They may be formed on bioclastic or quartz nuclei. Oolitic laminae on large shell fragments are not common.

Lignite is a common component of the sediment. It usually occurs as short logs up to about 30cm long but branches up to 1m. in length are occasionally present. Finely divided lignitic detritus is also common. In concentrations seen on fallen blocks on the

foreshore beneath Watton Cliff the logs do not show a strong preferred orientation.

The sheets and lenses occur in two main settings. The main occurrence is within the major calcirudite bodies of the formation, where they tend to occur towards the base and centre of the bodies rather than at the top; the tops tend to be composed of clearly cross bedded calcirudite of facies 12. This is clearly seen at Watton Cliff (fig. 21). Laterally extensive calcirudite sheets occur in facies associations A and D, more commonly in the former. These do not have clearly erosional bases and are often overlain by a thin veneer of calcarenite. The best exposed example, at 6.6m above the Boueti Bed at Watton Cliff, is 30cm thick at the east end of the cliff section and thins laterally to about 15cm at the west end where it contains a high proportion of quartz sand and calcarenite.

Interpretation

Examples of the facies within calcirudite bodies are characterised by the presence of marl drapes and they may have erosional bases and/or tops. This suggests that very high energy conditions must have existed intermittently. Marl interbeds up to 20cm thick show that low energy conditions must have been persistent at times. The presence of marl drapes on cross bedding surfaces suggests that the sediment was only intermittently mobile.

The hummocky cross-stratification occasionally observed in the calcirudites is comparable with that observed by Harms, Southard, Spearing and Walker (1975), Hamblin, Duke and Walker (1979) and Bourgeois (1980) and is interpreted as being generated by storm waves. This suggests that many of the calcirudite bodies may have been built up by storm waves, their cross-bedded tops being reworked by currents.

The thin, isolated sheets have sharp bases accentuated by cementation of the marl at the base of the bed, where shell fragments are embedded in it. These horizons are unlikely to be the products of winnowing of fine grained sediments for two reasons. Firstly they occur interbedded with fine grained sediments which show little evidence of wave or current action. Secondly the surrounding sediments do not generally appear to contain a fauna either abundant or varied enough to produce the calcirudites. Thus they must have been transported into the areas of deposition by currents, see pp. 145-6, table 5.

The shell debris is made up almost entirely of disarticulated valves and most of these are broken and worn, though occasional entire valves of Camptonectes with complete auricles are found, suggesting that the shell debris is derived rather than in situ but that at least a proportion of it is derived from a relatively close source.



Figure 20. Parallel scours in fine calcirudite. Fallen block on foreshore, Watton Cliff. Lens cap is 6cm. in diameter.



Figure 21. Section through calcirudite body, showing oppositely dipping cross-set of coarse calcirudite overlying irregular sheets and lenses of coarse calcirudite.

Facies 9.

Channel-fill facies

Channels in the Forest Marble have been described in some detail by Allen and Kaye (1973) from immediately below the Cornbrash at Shipton-on-Cherwell Quarry, Oxfordshire and by Palmer (1973) from Elm Farm Quarry, Stratton Audley, Oxfordshire. Channeling is also recorded at Foss Cross Quarry, Glos. (Klein, 1965) and at the base of the formation at Baggridge Hill (Penn and Wyatt, 1979).

The channel-fills at Shipton-on-Cherwell are of two types. The older is filled with 'calcarenite' and the younger with calcite-cemented quartz sand. The calcarenite fill is up to 2.6m. thick. The lithology is a coarse calcarenite composed largely of Neomiodon and Praeexogyra valves overlying a mudstone-intraclast, basal lag. The calcarenite fines upwards. The sand-filled channels are up to 1.05m deep and contain macerated plant debris on most laminae. Allen and Kaye (1973) suggest that they may record deposition in tidal channels close to land and, because of their incised character, suggest that more than one period of lowered sea level separated Forest Marble deposition from that of the Lower Cornbrash.

Channels are common in the study area and can be divided into two groups; those cut into marls and other fine-grained sediments and those cut into the calcirudite bodies themselves. These are thought to be of different origin and so are described here as separate subfacies.

Subfacies 1. Channel-fills in fine grained sedimentsDescription

Four channels which clearly cut into fine grained sediments have been recorded; at Henstridge (ST 711195), Watton Cliff (SY 455907), Bothenhampton (SY 477911) and East Cranmore (ST 694434). The channel-fills are all largely of calcirudite.

At Bothenhampton, the channel fill is 25m. wide and its maximum exposed thickness is 1.94m. The shape of the channel is broadly concave up. Accretion surfaces are approximately concordant with the channel margin and dip at up to 26° . The fauna of the channel-fill does not appear to differ from that of the remainder of the calcirudites in the area and is dominated by Praeexogyra and Apiocrinus fragments. The channel is cut into sediments of facies association A and overlain by facies association D. It is shown in figure 22.

At East Cranmore, two channel-fill units are present. On the north side of the cutting the lower unit is well exposed, but it is almost cut out by the base of the upper unit on the south side.

The lower unit is composed of a set of lateral accretion surfaces up to 1.2m. in height. These are composed of interbedded calcirudites, calcarenites and calcareous marls in beds between 2cm. and 20cm. thick. Most of the cross beds are lenticular rather than parallel sided and are graded across the width, each bed being composed of one or more coarsening and fining cycles. These vary between 1cm. and 2cm. in thickness and, when fully developed, show the sequence marl, quartz sand and/or ooliths, calcirudite, quartz sand and/or ooliths, marl (fig. 23). Marl drapes are particularly prominent on the accretion surfaces.

The accretion surfaces in the lower channel fill have a depositional dip of between 9° and 23° . On the south side of the cutting, the lower unit is represented only by calcarenites and marly limestones which have a similar depositional dip. No minor sedimentary structures indicative of current directions have been found on the accretion surfaces. The channel is cut into marls and heavily bioturbated silty sandstones of association A.

The upper channel fill is up to 1.17m. thick and cuts down into



Figure 22. Channel at Bothenhampton.

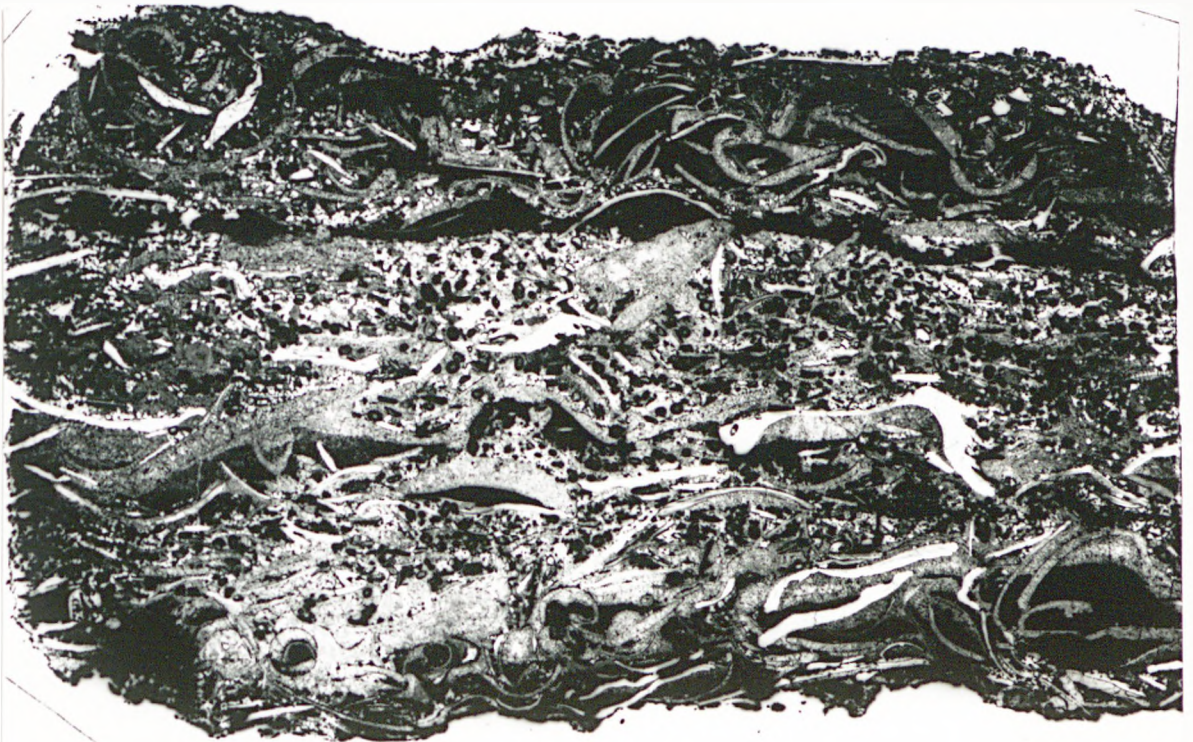


Figure 23. Positive print of acetate peel showing graded bedding in channel-fill sediments, lower channel-fill, East Cranmore. x 6.

the lower unit and underlying marls. It has a very well developed basal lag of well rounded marl intraclasts and large logs up to 12cm in diameter, set in a matrix of marl with scattered shell fragments and oolites. The marl intraclasts and matrix are stained red or dark brown by haematite. This staining is atypical of the intraclasts in the formation as a whole; they are usually stained by limonite. The railway cutting cuts the channel almost axially and it is not clear whether the calcirudites in the channel fill are cross-bedded. However, they appear to fill the channel concordantly with the basal erosion surface. The calcirudite is very well sorted and coarse-grained and contains marl and micrite intraclasts. The fauna includes many broadly stenotopic groups; echinoids, bryozoans and brachiopods are all seen in thin section. The dominant faunal elements appear to be Apiocrinus ossicles and Praeexogyra fragments.

Imbrication of the intraclasts suggests a palaeocurrent direction to approximately 085° . Orientation of logs in the channel lag are shown in figure 24, but these should be treated with caution as there is some suggestion at outcrop that the logs may be branches of a single tree or tree limb. The channel fills are shown in figure 25:

At Watton Cliff a small channel, at least 30cm thick, occurs above the main calcirudite bodies, about 3m below the cliff top. The cliff top is about the same level as the base of the Cornbrash, which was formerly exposed here. The channel has an irregular and clearly erosive base and is filled with a single cross-bedded set about 20cm thick overlain by finer grained, apparently plane bedded material, fig. 26. Unfortunately it is completely inaccessible.

At Henstridge Quarry, 25m from the north end of the east face, a cross-bedded sequence 1.7m thick is incised into marl. It is composed of parallel-sided, dipping units of coarse calcarenite

ORIENTATION OF LOGS IN UPPER CHANNEL-FILL,
EAST CRANMORE RLY. CUTTING.

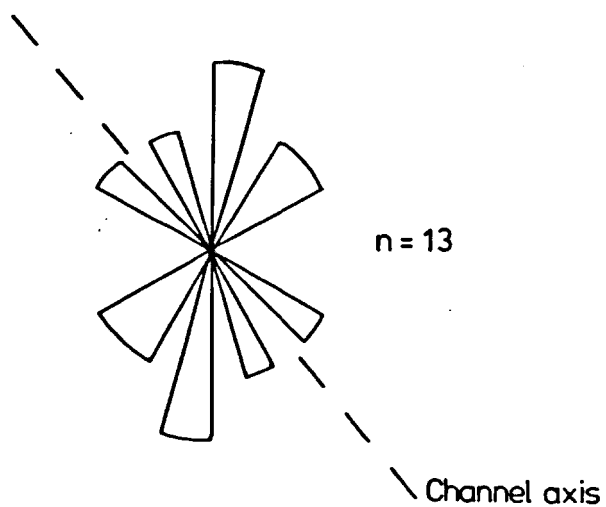


Figure 24. Azimuths of long axes of logs in upper channel-fill unit, East Cranmore.



Figure 25. Channel fills at East Cranmore. The upper unit (base at bottom of hammer handle) cuts out the lower unit, visible to the left of the photo, towards the right.



Figure 26. Small channel fill at Watton Cliff. Channel is about 30cm. thick.

and has no basal lag. The lateral extent of this channel fill is obscured by poor exposure, but it is not seen elsewhere on the east face of the quarry.

The faunas in the channel fills do not appear to differ from those of other calcirudite facies except in the case of the lower channel-fill at East Cranmore. Here superb exposure on mud-draped cross-beds allowed a detailed analysis of the fauna. Counts were made of all fragments where more than half a valve or specimen were present. In the case of bivalved taxa, all of which were disarticulated, only the left or right valves were included in the totals, depending on which were the most numerous. This was in order to prevent a numerical bias against univalved organisms. Results are shown in table 4.

Table 4 Fauna of the lower channel fill, East Cranmore Railway Cutting

Taxon	No. of individuals ^x	No. of valves [†]		Total	%
		Left	Right		
<u>Placunopsis socialis</u>		149	0	149	39.9
<u>Praeexogyra hebridica</u>		54	59	59	15.8
<u>Cycloserpula</u> sp.	45			45	12.1
<u>Lithophaga</u> sp.*	41			41	11.0
<u>Camptonectes annulatus</u>		23	19	23	6.2
<u>Dorsoserpula</u> sp.	13			13	3.5
<u>Tetraserpula</u> sp.	13			13	3.5
<u>Placunopsis</u> cf. <u>jurensis</u>		6	0	6	1.6
<u>Multisparsa lamellosa</u>	3			3	0.8
<u>Camptonectes laminatus</u>		2	2	2	0.5
<u>Oxytoma costatum</u>		0	2	2	0.5
<u>Modiolus imbricatus</u>		1	2	2	0.5
<u>Barbatia</u> sp.		2	2	2	0.5
<u>Radulopecten vagans</u>		2	2	2	0.5
<u>Lopha gregarea</u>		1	2	2	0.5
? <u>Ripisoecia</u> sp.	2			2	0.5
<u>Pseudolimea duplicata</u>		1	2	2	0.5
<u>Plagiotoma subcardiiforme</u>		0	1	1	0.3
<u>Plicatula</u> sp.		1	0	1	0.3
<u>Apiocrinus</u> sp.	1			1	0.3
<u>Cylindrites</u> sp.	1			1	0.3

Also present: Indet. micromorphic gastropods
High spired gastropods (as casts only)
Bryozoan and ? Clionid borings.

* Preserved as crypts in intraclasts only.

x All taxa except bivalves.

† Of bivalves.

The fauna from the lower channel fill at East Cranmore is dominated by the eurytopic bivalves Placunopsis socialis and Praeexogyra hebridica and contains very few echinoderm and brachiopod fragments compared to other calcirudite faunas. This suggests that it may possibly have been derived from an area of slightly less than fully marine salinity. This is in contrast to the faunas of the other channel fills, which do not differ in composition from other calcirudites.

Interpretation

The coarsening and fining rhythms present in the East Cranmore channel fill suggest deposition from currents of alternately high and low energy. It seems possible that this depositional regime could result from the passage of tidal currents. There is certainly other evidence of tidal currents in the calcirudites of the formation (pp.131-133). If these were, in fact, tidal channels, opposed tidal palaeocurrent indications would not necessarily be expected as tidal channels are often dominated by ebb or flood oriented bedforms, particularly ebb-oriented bedforms, as constriction of flow within the channel occurs as the tide falls, resulting in increased current velocities. Mud drapes are also characteristic of bedforms in tidal channels (Hoyt and Henry, 1967).

The channel faunas may support this interpretation. There is abundant evidence of land derived material (logs) and many eurytopic organisms in the sediments, but there are also elements suggestive of stenotopic conditions such as bryozoans and crinoids. Strongly mixed faunas are characteristic of tidal channels (Shepard, 1960).

The channel fills appear in many cases to be composed of lateral accretion sets. At East Cranmore this is suggested by the presence of elongate scours in the sediments underlying the lower channel fill at the north end of the railway cutting. These are parallel



Figure 27. Imbricated calcirudite, Henstridge Quarry, note pen for scale.

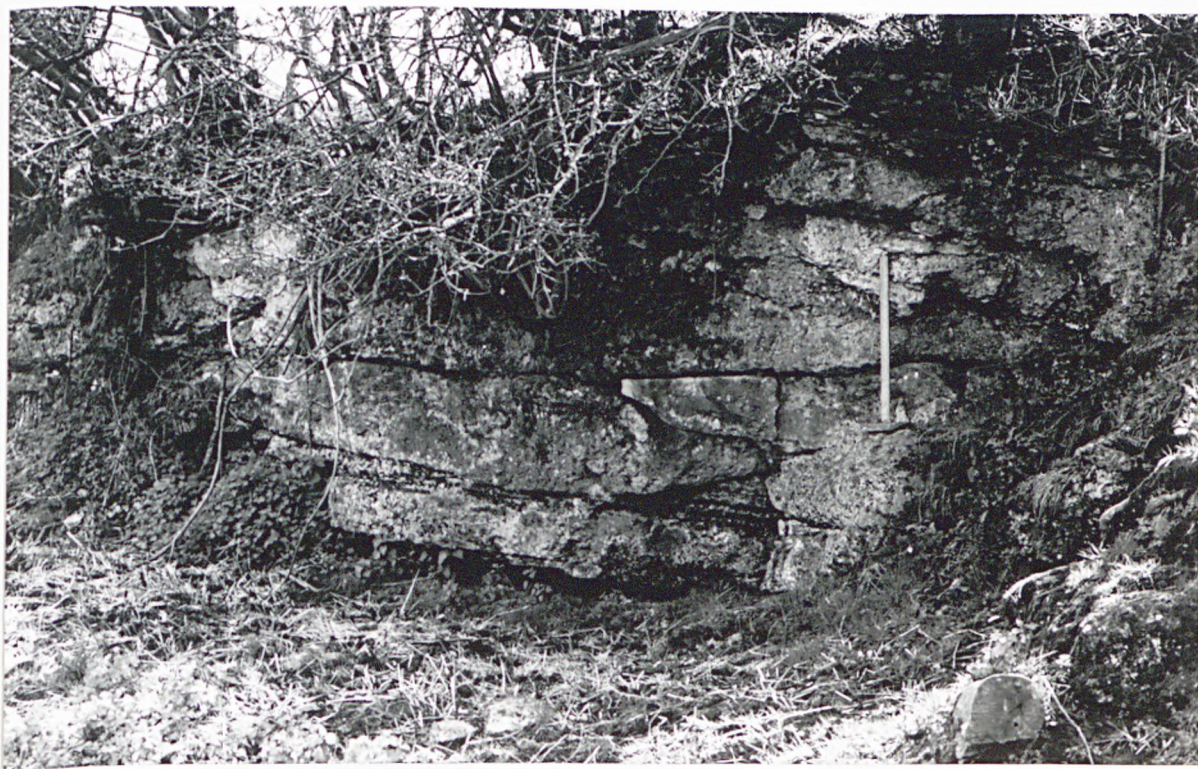


Figure 28. Channel within calcirudite body, Wanstrow Quarry. Hammer head rests on erosion surface.

to the strike of the cross-bedded fill and indicate an axial direction of about 140° for the channel. This suggests that the channels may have been sinuous to some degree, an interpretation that is quite compatible with the presence of two vertically stacked channels with quite different axial orientations at East Cranmore.

Subfacies 2. Channel fills in calcirudite bodies

Description

This subfacies is described on the basis of a single example, at Wanstrow Quarry (ST 710410).

The north face of the quarry shows plane-bedded calcirudite into which a small channel about 35cm. deep is cut (fig.28). It is overlain by a calcirudite set 1m. thick which is apparently flat-bedded to the west of the channel and cross-bedded to the east. The channel is only 4.5m. wide and shows no evidence of any internal partings and has no basal lag. No grading is apparent in the fill and grain size of the shell debris comprising the fill does not differ noticeably from that of the surrounding sediment. The composition of the fauna is similar to that of the sediments into which the channel is cut; it is dominated by bivalve and crinoid debris.

The narrow width of the channel suggests that the outcrop may be almost a transverse section through it, and thus that its axis may trend approximately north-south.

Interpretation

The absence of internal bedding and the similarity in all respects of the channel sediments and those that surround it suggest that the channel may have been cut and filled relatively rapidly with locally derived sediments.

Similar small channels occurring in calcirudite bodies of

positive relief are well documented in both fossil and Recent deposits. (Brenner and Davies 1973, 1974; Greensmith and Tucker, 1968, 1969).

In the Redwater Shale (Oxfordian) of Wyoming and Montana, channel-lag coquinoid sandstones occur cutting the tops of underlying cross-laminated or cross-bedded sandstones interpreted as submarine bars. They represent deep gouges cut to a maximum depth of 4m into the bar ridges in response to either storms or tides. The channels cut the bars obliquely at angles of between 30° and 90° to the ridge crests. The coarseness of the sediment in the channels is several orders of magnitude greater than the surrounding sediments and would clearly require stronger currents to transport it than would be needed to move the underlying sand grains. It is thus suggested that the channel lags represent short-lived high energy conditions and that the channels were cut by storm surge (Brenner and Davies, 1973).

On the basis of the lack of evidence for the permanence of the channel at Wanstrow and its position within a calcirudite body, it is considered probable that the channel was storm cut and that it may have been filled relatively rapidly by more normal (fairweather) processes.

Facies 10. Ripple cross-laminated calcarenite

Description

Within the facies association, ripples are confined to sediment in which the predominant maximum grain size is less than about 2mm. Ripples sediments frequently contain coarser material such as large bivalve fragments and macerated plant debris in the ripple troughs however.

Ripples normally form in a veneer of finer sediment on the top of calcirudite beds. No symmetrical wave ripples have been found but wave-straightened current ripples or shoaling wave ripples with more or less straight crest lines are common. Ripple height is normally low; the greatest observed is about 8mm. Ripple indices are normally 8 - 10. Consequently the ripples are very difficult to detect in cross section.

Interference ripples have been observed in loose blocks on the foreshore at Watton Cliff. Also at this locality diametrically opposed current ripples have been observed in the same ripple cross-laminated coset. One occurrence of a single ripple formed along the crest of a small dune was noted. This had its avalanche face diametrically opposed to that of the dune.

No in situ occurrences of ripples have been recorded. The vast majority of occurrences were seen at Watton Cliff, the only locality at which a supply of fallen rocks is present.

Interpretation

The ripples were probably formed predominantly by unidirectional currents, though some show the influence of wave action.

The occurrence of diametrically opposed ripples and dunes at Watton Cliff suggests that tidal currents may have been influential.

Facies 11.

Imbricated calcirudite

Description

Imbrication is rare in the calcirudites; it has only been recorded at Bruton Quarry (ST 693361) and Henstridge Old Quarry (ST 717185) and in small patches at Watton Cliff. It is formed by the oblique overlapping of shell fragments at an angle of about 45° .

At Henstridge imbrication persists throughout seven units of shell-detrital calcirudite, each up to 13cm thick. The orientation of the shell fragments is consistent between and within the various units, although small patches in most units have sharp bases and erosional tops and are separated by ripple quartz sands and calcarenites up to 2cm thick (fig. 27). Ripple orientation is consistent with the palaeocurrent directions given by the imbrication of the shell debris.

On the west face of Bruton Quarry and at Watton Cliff, small patches of imbricated calcirudite up to 1m. in length and 2cm. thick are present.

No vertically oriented shell debris has been seen within the study area, but it may occur within facies 13 at Leigh Delamere, near Cirencester.

Interpretation

Reference to imbrication in shell debris are largely confined to vertically imbricated material, e.g. Greensmith and Tucker (1968), Farrow (1974), Grinell (1974), Seilacher and Meischner (1964). However, obliquely imbricated shell debris is very easily produced in flume experiments, see Appendix 3.

It is considered that the obliquely imbricated calcirudite is the product of fast flowing unidirectional currents. Why this structure is not more common in the calcirudites is not known. One may speculate that the effects of variation in pressure and of orbital water motion, produced by passing waves, may have had a significant effect in breaking up imbrication or preventing its formation. The presence of small scours, similar to those observed in flume experiments, suggests that current speeds were at least intermittently sufficient to produce imbrication in the shell debris.

Facies 12. High angle, cross-bedded calcirudite

Description

Set thickness varies between 4cm. and 2m. in this facies, though the vast majority of sets are between 20 and 50cm. thick. Cosets up to 2m. thick are seen, e.g. at Bruton Quarry (ST 693362), fig. 29. Foreset angle is $>5^\circ$.

The majority of sets are lenticular in shape with tangential foreset laminae, although a few tabular sets have been seen at Watton Cliff.

The most common occurrence of the facies is as single sets or cosets at the tops of calcirudite bodies (fig. 21). Large cosets with unidirectional palaeocurrents, such as occur at Bruton Quarry, are not common. Bidirectional cosets are more frequent, e.g. at Cock Road Farm (ST 761526) and Marston Bigot Quarry (ST 758452).

The thinner sets show a tendency to occur in finer sediment. It seems unlikely that very coarse shell debris is suitable for the formation of such cross bedding.

Interpretation

The facies is probably produced by the migration of dunes. In many cases the presence of troughs is suggested by the lenticularity of the sets, though unequivocal trough cross-bedding has not been seen.



Figure 29 High angle unidirectional cross-bedding in calcirudite,
Bruton Quarry.

Facies 13. Giant scale cross-bedded calcirudite sets

Distribution

This facies is described on the basis of only two examples; at Swyre Quarry (SY 520880) and, outside the study area, at Leigh Delamere Service Station on the north side of the M4 motorway near Cirencester.

Description

The quarry at Swyre, which was almost completely infilled in November 1979, was composed of a single face largely occupied by a single, cross-bedded set between 6 and 7 metres thick. The top of this set is still exposed and attempts to dig out the base showed that it extended for at least another 80cm. beneath the quarry floor.

The top of the set is bounded by a slightly ironstained undulatory erosion surface and is overlain by 1m. of lenticularly bedded calcarenites, fine quartz sands and marls of facies association D.

The tops and bases of the foresets are slightly undulatory and occasionally slightly erosional. In most cases they are composed of shell fragments lying parallel to the foreset dip. However, particularly at the west end of the quarry, certain foresets are composed of shell fragments lying obliquely at a high angle to the dip of the foreset surfaces in a similar manner to those from Leigh Delamere (fig. 30). These foresets have considerably more micrite in the matrix than is normal in the facies.

The orientation of the long axes of the shell fragments on the flat-bedded foreset surfaces is shown below (fig. 31). Two modes are present; one parallel to the direction of dip and the other almost at right angles to it, i.e. horizontal. This pattern is typical of the orientation of shell debris in unidirectional flows



Figure 30. 'Imbricated' calcirudite within erosively based major foresets of Facies 13, Leigh Delamere Service Station. Note steepening of 'imbrication' up dip.

ORIENTATION OF SHELL FRAGMENTS ON
LARGE SCALE CROSS BEDDING SURFACE,
SWYRE QUARRY.

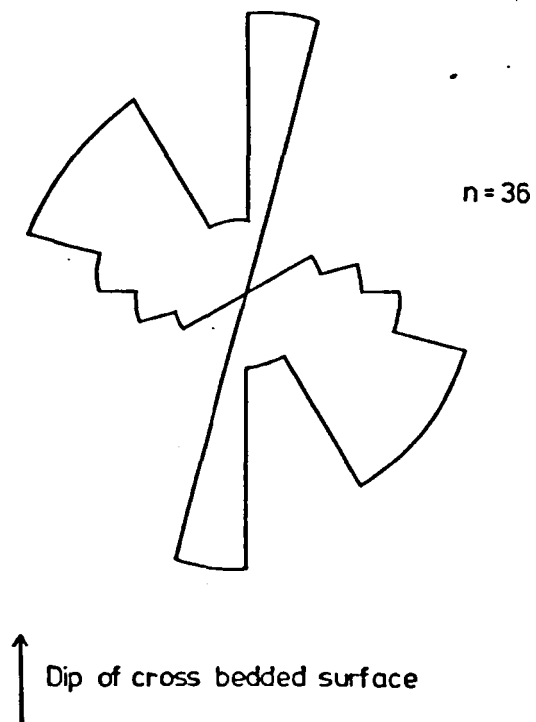


Figure 31 .

in flume experiments, suggesting that there was a component of flow down the foreset surfaces.

A major discontinuity surface divides the quarry into two parts, a lower (westward) shallowly dipping part, overlain by more steeply dipping foresets to the east, (fig. 32).

Small natural exposures to the west of the quarry indicate that the set continues for at least 500m to the west. Large scale cross bedding can also be seen 1km east of the quarry at West Hill, West Bexington, but this is probably not continuous with that at Swyre.

The fauna of the facies is very difficult to analyse due to a high degree of cementation. It appears to be dominated by oyster fragments. Wilson et al. (1958) record Mactromya varicosa and Lissochilus buvignieri. The erosion surface at the top of the set is not colonised.

Outside the study area, at Leigh Delamere Service Station (ST 890791), an extremely good exposure in very similar sediments is seen on the west face of the quarry. At the north end of the face, a very large cross-bedded set more than 7m thick is exposed. To the south this is overlain by a series of wedge shaped, climbing, cross-bedded sets in which herring-bone cross-bedding is present (figs. 33, 34).

Minor cross-bedded sets climb up the foresets of the large set (fig. 35). These occur only towards the base of the quarry and may indicate either bedforms produced by backflow at the toe of the large set or small dunes, produced by a current flowing in approximately the opposite direction to the dominant flow responsible for the large set.

Laminae of quartz sand are also present between the foresets,



Figure 32. Large scale cross-bedding, facies 13, Swyre Quarry.
(This very poor photograph is the only record of this
quarry, levelled in 1979).

thickening towards the set base. The base and tops of the foresets are sometimes erosional and often swell and pinch slightly.

Although most of the shell debris in the foresets is flat-bedded, in the foresets with the most obviously erosional bases, the shell fragments are apparently imbricated at a steep angle to the cross bedding. This 'imbrication' steepens up dip (fig.30).

Major discontinuities are also present in this section (fig.33).

Interpretation

The bipolar palaeocurrent directions recorded from both the climbing, cross-stratified, wedge shaped sets and the giant cross-bedded set at Leigh Delamere can leave little doubt that the bedforms were strongly influenced by tidal currents. The similarity of the two exposures suggests that the giant set at Swyre is of similar origin.

It is suggested that the large bedforms are probably tidal sandwaves. These may be defined as large asymmetrical bedforms greater than about 1.5m in height which may have a lee slope angle less than the angle of repose (Johnson, 1978, p.217).

Transport up the lee slope is a common feature of Recent sandwaves (Terwindt, 1971). Low-angle cross-stratification of the major foreset surfaces, important discontinuities between depositional units, slightly sinuous foreset traces and internal erosion surfaces have been observed in ancient sandwave sequences (Nio, 1976) especially in his post-sandwave facies.



Figure 33. Large scale cross-bedding, facies 13, Leigh Delamere Service Station.



Figure 34. Herring-bone cross-bedding, Leigh Delamere Service Station. Ruler is 30cm. long.



Figure 35. Oppositely dipping parasitic bedform on major foresets of facies 13, Leigh Delamere Service Station.

Facies 14.

MicritesIntroduction

Thin micritic limestones are common both immediately above and below the calcirudite bodies, e.g. at East Cranmore and Watton Cliff and immediately above the Digona Bed at Langton Herring Quarry. They are included in this facies association because of their field association with the calcirudites.

Description

The facies is composed of impure yellow or grey micritic limestones occasionally containing wisps and laminae of quartz silt and sand. Beds are up to 40cm thick.

The micrites are usually highly bioturbated with Thalassinoides the only recognisable ichnogenus.

In most cases an infauna of Vaugonia moretoni, Nicaniella (Trautscholdia) cordata and Palaeonucula waltoni is present. In some cases fragments of an epifauna are preserved, often as shell debris in bioturbation structures. At Watton Cliff, Tetraserpula sp., Radulopecten vagans, Praeexogyra hebridica and Digonella digona were recorded, whilst in the micrite overlying the Digona Bed in Langton Herring Quarry ? Isognomon isognomonoides (Stahl) was found in addition to the taxa listed above.

Approximately 30cm below the calcirudites at East Cranmore is a thin micrite heavily encrusted by Cycloserpula sp. and with a current aligned fauna composed of:

Nicaniella (Trautscholdia) cordata

Pseudolimea duplicata

Dacryomya lacryma

Placunopsis socialis

Anisocardia sp.

Isocyprina bella

? Procerithium sp.

? Alaria sp.

Indet. scaphopods

Interpretation

The micrites were probably laid down when finegrained terrigenous sediment influx was relatively low. Junctions with marl units are usually quite sharp, suggesting that changes in the proportions of carbonate fines to terrigenous fines occurred quite quickly. The increased amounts of carbonate material may well have been derived from the large shell accumulations with which they are associated. These shell bodies may also have acted to cut off supply of terrigenous material in some way.

It is interesting to note the differences in fauna between the marls and the micrites. The micrites have a fauna which resembles that of the firmgrounds rather than the unconsolidated marls of facies association A. They are intensely burrowed and contain infaunal bivalves as well as epifaunal elements. This suggests that the sediment was better oxygenated than during marl deposition, perhaps because less organic matter was present which could be oxidised bacteriologically.

As stated earlier, the calcirudite sequences can be divided into four broad categories:

1. Isolated single beds less than 40cm. thick.
 2. Sequences composed largely of flat-bedded and cross-bedded sheets and lenses of calcirudite forming units up to 10m. thick.
 3. Channel sequences.
 4. Giant cross-bedded sequences.
- 1) The simplest calcirudite bodies are isolated beds found in the marl dominated sediments of facies association A and occasionally in facies association D. The best exposed example, at Watton Cliff, thins westward into a calcarenite with a high quartz sand content, suggesting that it is a wedge- or lens-shaped unit.

Shell pavements and sheets are known to originate from the degradation of shell banks in prolonged or severe storms in shallow submarine and intertidal settings (Greensmith and Tucker, 1969; Farrow, 1973). For example shell sheets at the northern end of Ray Sand, Thames Estuary, are thought to originate in this way (Greensmith and Tucker, 1969, p.413). It seems quite likely that some of the Forest Marble shell sheets may have originated in a similar way, as thick calcirudite bodies are present to provide source material.

Another possibility is that some of the isolated beds may simply be the feather edges of larger calcirudite bodies. This is not particularly likely at Watton Cliff, where a single, isolated sheet is present, but sequences such as that at Redlynch, where some amalgamation of thin calcirudite beds may occur, could have formed in this way. At Cogden Farm Quarry, a thick calcirudite body exposed on the south face appears to pass laterally into strongly wedge-shaped

calcirudite horizons interbedded with marl on the east face. These are strongly suggestive of shoal edge deposits.

In all cases it seems unlikely that the isolated beds originated directly from the destruction of an adjacent living community. The shell debris is always completely disarticulated and most grains are broken and rounded. Where an adjacent in situ fauna is present, its composition is not reflected in the shell debris. At Redlynch, for example, where the Boueti Bed immediately underlies calcirudite horizons, none of the characteristic brachiopods of the Boueti Bed are found in the calcirudites. Thus the probability is that these horizons are derived from other calcirudite bodies.

Sequences composed largely of flat-bedded and cross-bedded sheets and lenses are extremely common in the study area and may be up to 10m. thick, e.g. at Charlton Horethone (ST 669240).

2) Where the bases of such units are exposed they are always sharp but seldom clearly erosional. This supports the contention of Allen and Kaye (1973) that the majority of the calcirudite bodies in the Forest Marble are of a positive rather than Channel-like relief, as they have a generally plano-convex shape and, in many cases, non-erosional bases. Klein (1965) suggested that, in the Oxford area, the calcirudite bodies were formed in meandering channels cut in a tidal flat. Though channels are certainly present in the Forest Marble throughout its outcrop, they are not nearly as common as shell bodies without erosional bases. Thus Klein's interpretation does not seem to be widely applicable, especially in the study area, where the sediments that surround the calcirudite bodies are thought to be, for the most part, subtidal rather than intertidal in origin.

Where tops of such bodies are exposed, they always display a gradational change from calcirudite via mixed calcirudite/marl

sequences into mixed quartz sand and marl lithologies. This may be seen at Watton Cliff, Cogden Farm and Baggridge Hill. An extremely detailed section illustrating such a transition is shown in figure 28.

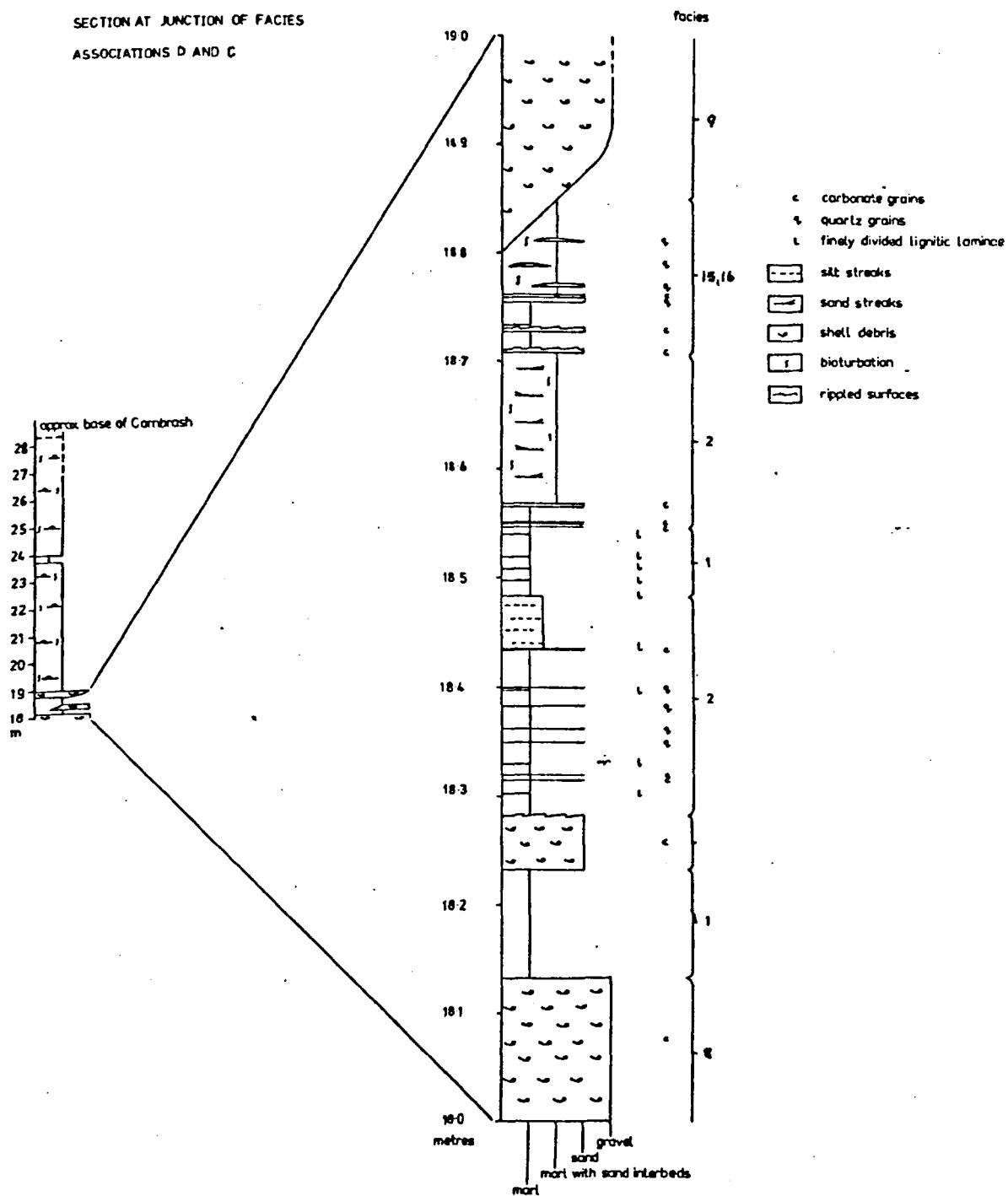
Marl partings and interbeds are very common in the sequences. These probably provided source material for many of the marl intra-clasts. Marl partings may be widespread, e.g. that dividing the two calcirudite bodies at Watton Cliff (at 16.2m. above the Boueti Bed, fig. 13), or of very local extent, frequently being cut out by the amalgamation of two calcirudite beds.

Widespread marl partings have been identified in the calcar-enites at Shipton-on-Cherwell Quarry, Oxon. Here they have been used to estimate the maximum relief of the calcirudite body (equal to the maximum thickness between marl partings) (Allen and Kaye, 1973). Using this method, the thickness of the calcirudite body at Watton Cliff is estimated to have been less than 2m., a very similar thickness to that at Shipton-on-Cherwell.

Although no clear sequential organisation is visible in the calcirudite bodies in most quarries, important features of some of the best exposures suggest that many of them may represent large shoals.

At Watton Cliff, the calcirudite sequence in the central part of the succession can be divided into three parts; two calcirudite bodies overlain by a small, calcirudite-filled channel. The lower calcirudite body is best examined near Fault Corner, at the west end of the section. Here it can be clearly seen to be composed, at least in part, of 'hummocky' cross bedding, the bedding being picked out by grain size differences. Immediately to the east of Fault Corner this appears to pass laterally into irregularly bedded material which contains dominantly northerly dipping cross beds.

WATTON CLIFF
SECTION AT JUNCTION OF FACIES
ASSOCIATIONS D AND C



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The basal part of the upper calcirudite body appears to be composed of a similar sequence, containing both hummocky cross-bedding and northerly-dipping cross-bedding. It must be emphasised that these are only elements of the sequences and that flat-bedded horizons, low angle cross-bedding and lenses with markedly erosional bases and/or tops are also present. The upper calcirudite body is overlain by one, or in places, two oppositely dipping, cross-sets up to 25cm. thick. These are of rather irregular thickness and have slightly erosional bases and are probably trough sets. Thus at least the top 0.4 - 0.5m. of the shell body was influenced by currents which may well have been tidal in origin.

This apparent reworking of the tops of the calcirudite bodies by currents is a common feature. It also occurs at Langton Herring Quarry, Canal Quarry, Bradford-on-Avon and at Henstridge Old Quarry.

The irregular cross stratification, so common in the calcirudite bodies, is of unknown origin. It can be broadly compared with the structures seen in washover deposits (Schwartz, 1975) but the resemblances probably arise simply because the calcirudite bodies are composed largely of interfingering and sometimes erosive lobes of sediment. These may have originated by washover or spillover processes, but equally they could simply be reflections of an irregular shoal topography. Occasionally this cross-stratification is interrupted by hummocky cross bedding, suggesting reworking by storm waves (Harms et al., 1975).

The presence of marl partings indicates that high energy conditions were intermittent and thus that shell debris may only have been mobile during high energy storm conditions.

At Wanstrow Quarry (ST 710410), the calcirudite body is cut by a small channel thought to be of storm origin. This is overlain

by a broadly cross-stratified set which passes laterally into apparently flat-bedded calcirudite (fig. 28). This set is typical of the irregular cross-bedded sheets and lenses and may possibly reflect the migration of surface features on the shoal.

The calcirudite sequences described above are broadly comparable with those of offshore intertidal shell banks near the Essex coast, e.g. the Sales Point offshore bank. These are composed of flat lying sheets and lenses of shells and sand up to 1m. thick surmounted by ridges of mobile shells also up to about 1m. thick. The shell debris is allochthonous and poorly sorted. The mobile shell layers may be cut by broad shallow channels produced by storm action. Dunes are not recorded in this coarse shell debris (Greensmith and Tucker, 1973, p.407).

It is assumed therefore that the sequences composed largely of sheets and lenses of cross-bedded and flat-bedded calcirudite represent shell banks or shoals built up in shallow water from allochthonous shell debris.

There is no evidence of emergence of these shoals but it is interesting to note that many of the calcirudite bodies, particularly those at Watton Cliff, are very rich in logs. Although finely macerated plant debris is very common throughout the Formation, logs are very rare outside the calcirudites. If the logs are confined to the channels and shoals it suggests the possibility that they may have been stranded on the shoals by temporary emergence. As finely divided plant debris occurs in varying quantities throughout the Formation, it seems unlikely that all the logs in the calcirudites simply sank as a result of waterlogging as this might be expected to produce a more even distribution within the sediments of the Formation as a whole.

The channel sequences which are cut into sediments of association A

occur in sections in which no shoal sequences are seen, except at Henstridge, where the channel is overlain by calcirudite sheets and lenses. Thus, at least in the case of the channels at East Cranmore and Bothenhampton, they probably occurred between shoals. The sequence at Henstridge may indicate lateral migration of a small shell body over a channel.

It seems therefore, that the majority of the calcirudites can be explained as a series of shoals, tidal channels and associated shell sheets occurring in a shallow marine setting. In such a setting, tidal deltas might be expected but these have not been identified. Instead, they are associated with sequences interpreted as tidal sandwaves. I originally considered that these sequences might represent tidal deltas as they show many of the features that might intuitively be expected in such sequences. They show steeply imbricated, erosively based foresets which might be interpreted as slumped delta foresets. Also present are both quartz sand laminae (possibly derived from Association D) and shell debris, implying mixing of source materials. The presence of large discontinuities within the giant cross bedded sequences might possibly be interpreted as resulting from the overlapping of lobes of sediment produced by delta switching. However, the height of these sets; up to about 8m., indicates that they would have to prograde into at least that depth of water at the mouth of a tidal channel, and thus that there must have been a very steep palaeoslope immediately seawards of the channels (and presumably associated shoals). Also they bear little resemblance to tidal delta sequences described from the Recent, (e.g. Hine, 1975; Reinson, 1979) and closely resemble descriptions of both Recent and ancient sandwaves.

Unfortunately little information about the three-dimensional

geometry of the calcirudite bodies could be obtained. Although there is often a prominent scarp at the level of the calcirudites it has not proved possible to define this feature closely enough to map individual shell bodies. This suggests that the shell bodies may be imbricated against each other to form a fairly continuous sheet, though in detail it can be shown that calcirudite bodies occur at slightly different levels within the Formation.

In general terms the calcirudite sequences are uniform within the study area, i.e. no facies seems to be confined to any particular geographical area. This suggests that either widespread uniform conditions suitable for the development of tidal channels and shell bodies were developed or, alternatively, that the Formation was diachronous. The available evidence seems to favour diachroneity. Many of the shoal tops show current reworking of the top 50cm or so. This would suggest remarkably even water depths within the area and perhaps a widespread similar current regime. Secondly, characteristic fossils of the Boueti Bed have been recorded in the calcirudites at Watton Cliff. These include two disarticulated valves of G. boueti and specimens of Arcomytilus asper, neither of which have been recorded from any other in situ faunas in the study area.

Palaeocurrent data throws little light on the question of a shoreline direction, though it may give a rather approximate guide to shoal elongation if interpreted with caution.

Perhaps the most useful palaeocurrent data is the axial trend of the channel that cuts through the shoal at Wanstrow Quarry, which runs north-south. Storm cut channels may cut shoals at angles between 30° and 90° to shoal axes (Brenner and Davies, 1973), suggesting an east-west shoal elongation for the Forest Marble examples.

The sandwave sequences show palaeocurrent directions centred around 117° at Swyre, 141° at a small exposure near Cogden Farm, and a mode of 265° at Limekiln Hill, some 2km, east of Swyre. Since sandwave crests run essentially normal to the direction of tidal flow (Nio, 1976), southeasterly and southwesterly flowing tidal currents are indicated. It is probable that the correlation between sandwave crest orientation and tidal current flow is fairly low and perhaps it is only safe to assume a generalised southward palaeocurrent direction from these observations.

The orientation of the trough cross sets at the top of the calcirudite bodies at Watton Cliff suggest a similar current direction to the sandwaves at Swyre; three readings of 118° , 120° and 130° were taken. Where two cross sets are present at the top of the upper calcirudite body, the top set was seen to dip north or northwest.

The intershoal channels at East Cranmore and Bothenhampton show axial trends of 140° , 85° and 24° respectively.

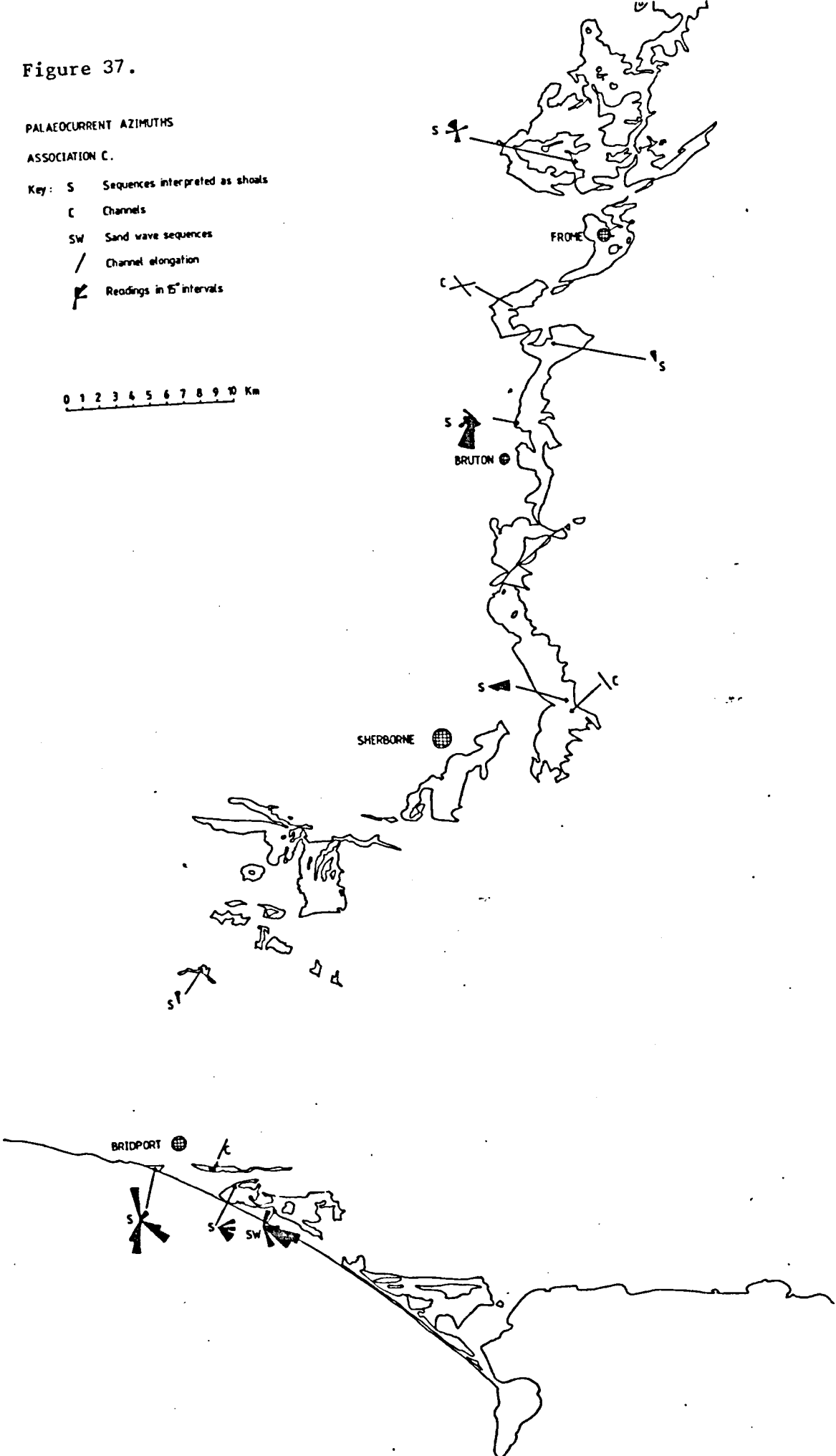
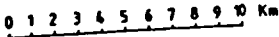
Other palaeocurrent data have been derived almost exclusively from facies 8 in shoal sequences. This includes many readings from low angle sets, introducing a high chance of inaccuracy to the data as it is assumed that all low-angle sets had a depositional dip downcurrent rather than perpendicular to current. Multidirectional palaeocurrent patterns are present in nearly all localities. Palaeocurrent data is summarised in figure 29.

The palaeocurrent patterns shown by most modern and ancient shallow marine, linear sand bodies are parallel to the body crests and unidirectional (Johnson, 1978, p.246, fig. 9.40). Exceptions to this do exist however, e.g. the tidal sand ridges of the southern North Sea (Houbolt, 1968) in which a bidirectional palaeocurrent pattern is present, and the sand bars of the Oxfordian of Wyoming

Figure 37.

PALAEOCURRENT AZIMUTHS
ASSOCIATION C.

- Key: S Sequences interpreted as shoals
C Channels
SW Sand wave sequences
/ Channel elongation
F Readings in 15° intervals



and Montana (Brenner and Davies, 1974) in which a multidirectional pattern is present.

Wave ripples have only been seen in loose blocks, so no crest orientations are available.

DERIVATION OF THE SHELL DEBRIS IN FACIES ASSOCIATION C

The molluscan species present in the shell debris of facies association C were compared with those of the in situ faunas of the Formation as a whole in the hope that it would be possible to determine whether any of the shell debris was derived from outside the Formation and whether it was derived from the faunas of associations B, C or D or some combination of the three.

Table 5 is a comparison of the molluscan faunas of associations B and D with species recorded in the shell debris of association C. In order to try and make the comparison as complete as possible, records of occurrences in the study area from Cox and Arkell (1948 - 1950) were added to my records. Of the localities mentioned by Cox and Arkell the vast majority are in the calcirudites alone. Two; the Hinton Sands at Hinton Charterhouse and their locality at Farleigh Hungerford, are known to be in association D. Records from the Boueti Bed and Bradford Clay are itemised separately by Cox and Arkell and have been added to the list of fauna from association B.

No comparison was made with the in situ faunas of association C; only Isocyprina bella and Alaria sp. are confined to these faunas and both are only represented by a single specimen.

As may be seen from Table 5, only 10 Bivalve species and 8 Gastropods are known from association C alone; 16.4% and 38% respectively of the species totals for the study area. Of the Bivalve species only Falcimytillus sublaevis could be considered to be at all common, in fact this is the only species seen at outcrop by me in the calcirudites that does not occur in other facies associations. Among the Gastropods, collection failure is likely to account for much of the differences as they are very poorly represented

in numerical terms in the calcirudites. Even where they can be seen they are frequently preserved only as steinkerns.

The comparison indicates that certainly the majority of the shell debris was probably derived from the autochthonous faunas of the Formation and could have been derived from within the study area. Secondly, unless the shell debris is assumed to be derived from the faunas of both associations B and D, there is a very poor correlation between the in situ and derived faunas. This is a strong argument for the diachroneity of the Formation when the distribution of the facies associations is taken into account (fig. 57).

It is uncertain whether any organisms colonised the shell bodies. No cementing organisms have been found on uncemented calcirudite. Of the species found in the calcirudites there is some possibility that grazing gastropods could have lived on the shoals, either grazing on algal films on the shell debris or living on attached seaweed. Perhaps the most likely organisms to adopt this mode of life are the micromorphic gastropods. These are often found in small patches in the calcirudites. They are 2 - 3mm long and are generically and specifically indeterminate. Their patchy distribution and abundance in the calcirudites suggest that they may have lived on the shoals. Some small boring organisms may also have lived in the loose shell debris as up to 68% of shell fragments may be bored. Bryozoans appear to be responsible for many of these borings.

Table 5. Comparison of molluscan faunas of Associations B and D with the species recorded from Association C (Calcirudites).

<u>Bivalvia</u>	Assn B	Assn D	Assn C
<u>Palaeonucula variabilis</u> (J. de C. Sow.)*			X
<u>Palaeonucula waltoni</u> (Morris & Lycett)	X	X	X
<u>Dacryomya lacryma</u> (J. de C. Sow.)	X		X
<u>Parallelodon hirsonensis</u> (d'Archiac)*		X	X
<u>Eonavicula minuta</u> (J. de C. Sow.)*	X		
<u>Eonavicula gibbosa</u> (Rollier)*			
<u>Barbatia pratti</u> (Morris & Lycett)	X		X
<u>Modiolus imbricatus</u> J. Sow.	X		X
<u>Falcimytillus sublaevis</u> (J. de C. Sow.)		X	X
<u>Arcomytillus asper</u> (J. Sow.)	X		X
<u>Lithophaga fabella</u> (J. A. Eudes-Deslong.)	X		X
<u>Oxytoma costatum</u> (Townsend)	X		X
<u>Oxytoma inequivalve</u> (J. Sowerby)*	X		X
<u>Pteroperna costatula</u> J. A. Eudes-Deslong.*		X	
<u>Costigervillia crassicosta</u> (M. & L.)			
<u>Gervillella acuta</u> (J. de C. Sow.)	X	X	X
<u>Gervillella ovata</u> (J. de C. Sow.)		X	X
<u>Gervillella monotis</u> (J. A. Eudes-Deslong.)	X	X	X
<u>Isognomon isognomonoides</u> (Stahl)		X	
<u>Radulopecten hemicostata</u> (M. & L.)	X		X
<u>Radulopecten vagans</u> (J. de C. Sow.)	X		X
<u>Radulopecten wollastonensis</u> (Lycett)	X		
<u>Camptonectes laminatus</u> (J. Sow.)	X	X	X
<u>Camptonectes annulatus</u> (J. Sow.)	X	X	X
<u>Camptonectes retiferus</u> (M. & L.)	X		X
<u>Plesiopecten subspinosus</u> (Schlotheim)*		X	
<u>Velata tegulata</u> (M. & L.)*	X		
<u>Plicatula fistulosa</u> Morris & Lycett	X		
<u>Plicatula waltoni</u> (Lycett)	X		X
<u>Placunopsis socialis</u> (M. & L.)	X		X
<u>Plagiostoma subcardiiforme</u> (Greppin)	X		X
<u>Pseudolimea duplicata</u> (J. de C. Sow.)	X		X
<u>Praeexogyra hebridica</u> (Forbes)	X		X
<u>Liostrea wiltonensis</u> Lycett	X	X	X
<u>Catinula ancliffensis</u> Cox & Arkell	X		?
<u>Exogyra crassa</u> (W. Smith)	X	X	X
<u>Nanogyra nana</u> (J. Sow.)	X		X
<u>Lopha marshi</u> (J. Sow.)*	X		X
<u>Lopha gregarea</u> (J. Sow.)		X	
<u>Trigonia elongata</u> J. de C. Sow.	X		X
<u>Vaugonia moretoni</u> (M. & L.)	X		
<u>Vaugonia detrita</u> (Terquem & Jourdy)*	X		X
<u>Astarte</u> (Coelastarte) <u>compressiuscula</u> M. & L.*	X		X
<u>Prorokia rustica</u> (M. & L.)*			X
<u>Eomiodon fimbriatus</u> (Lycett)		X	X
<u>Anisocardia loweana</u> (M. & L.)		X	
<u>Anisocardia davidsoni</u> (Lycett)		X	X
<u>Anisocardia truncata</u> (Morris)*		X	
<u>Sphaeriola oolithica</u> (Rollier)*	X	X	
<u>Mactromya varicosa</u> (J. Sow.)*			X
<u>Tancredia suburtansata</u> Lycett*			X

Bivalvia (continued)

Assn B Assn D Assn C

<u>Tancredia marmorea</u> Cox and Arkell*			
<u>Isodonta woodwardi</u> (Lycett)*		X	
<u>Quenstedtia bathonica</u> (Morris and Lycett)*			X
<u>Protocardia stricklandi</u> (Morris & Lycett)*			X
<u>Corbula buckmani</u> Lycett*		X	X
<u>Corbula hulliana</u> Morris*			X
<u>Myopholas acuticosta</u> (J. de C. Sow.)*		X	X
<u>Pholadomya lirata</u> (J. Sow.)			X
<u>Osteomya dilata</u> (Phillips)*	X		
	X		

Gastropoda

<u>Pleurotomaria burtonensis</u> Lycett	X		
<u>Symmetrocapulus tessonii</u> (Deslong.)*			
<u>Ataphrus labadyei</u> (d'Archiac)			X
<u>Ataphrus comma</u> (Lycett)			X
<u>Amberleya bathonica</u> Cox and Arkell		X	
<u>Heliacanthus tegulatus</u> (Lycett)*		X	
<u>Oolitica phillipsi</u> (M. & L.)*			X
<u>Riselloidea biarmata</u> (Munster)			X
<u>Proconulus burtonensis</u> (Lycett)	X		
<u>Metriomphalus hamptonensis</u> (M. & L.)*	X		
<u>Neritopsis guerrei</u> (Hebert & Deslong.)*			X
<u>Lissochilus bicinctus</u> (Phillips)*		X	
<u>Neridomus cooksoni</u> (Deslong.)*		X	X
<u>Neridomus costulata</u> (Deshayes)	X		
<u>Paracerithium costigerum</u> (Piette)	X		
<u>Lamelliphorus burtonensis</u> (Lycett)*			X
<u>Piettia denticulata</u> (Piette)*			X
<u>Ampullospira sharpei</u> (M. & L.)*		X	
<u>Cylindrobullina suessa</u> (Lycett)*		X	X
<u>Cylindrobullina luidii</u> (Morris)*	X		X

* records from Cox and Arkell (1948 - 50) not from personal collections

This Association is composed principally of interbedded sandstones and marl. Sandstone horizons vary from lenses $\leq 1\text{mm}$ thick to sand bodies up to at least 8m thick. Typically a range of wave- and current-produced sedimentary structures are preserved in the sandstones. A well-preserved, diverse ichnofauna is also usually present and rarely a well-preserved autochthonous macrofauna may be found. Allochthonous fauna is limited to sand size shell fragments and occasional disarticulated bivalves.

The facies that make up the Association have been defined principally on the composition and thickness of sand bodies and on the associated sedimentary structures.

Facies 1. Calcareous marl

Slightly silty calcareous marl is the background sediment in which the sandstones occur. The marl in the Association varies in colour from grey to brown to olive green. It is noticeable that colour variation is greater in exposed sections than in borehole material and thus that it may be induced or accentuated by weathering. Thick developments of marl without silt and sand wisps are rare. No horizons > than 15cm thick have been found, but thin developments interbedded with Facies 2 are very common and may form sequences up to 2m thick.

Facies 2. Silt-streaked marl

Very thin silt and sand streaks are extremely common in the Association. These are not normally persistent for more than 30cm laterally and are usually 0.5 - 2.0mm thick, though they may be up to 1cm thick. In many sections they are associated with bioclastic sands composed dominantly of bivalve, echinoderm and ostracod debris. They are frequently overlain by a drape of finely macerated

plant debris. The streaks usually have a lensoid shape suggestive of discontinuous incipient ripples. They are frequently highly bioturbated.

Facies 15. Lenticular bedded sands

Sand lenses with flat or wavy bases may be found interbedded with Facies 1 and 2. These normally consist of horizons of asymmetric ripples some of which appear to be unidirectional current ripples. The majority though, show either form discordance or evidence of interference patterns and are thought to be wave formed. Lenses are commonly stacked in phase on top of one another (Fig.38). The bases of lenses are frequently loaded. Lenses are normally bioturbated, particularly at the bases and tops.

Interpretation

A tendency towards superposition of lenses and discordancy of ripple form are two of the criteria used to distinguish wave ripples from those attributable to non-oscillatory unidirectional currents (de Raaf, Boersma and van Gelder, 1977). It is clear therefore, that much of the lenticular bedding was produced by wave action although unidirectional form-concordant sets indicate that unidirectional currents were also active.

The relative proportions of lenses attributable to waves and unidirectional currents have not been quantified due to poor exposure. However, the impression gained from abundant loose blocks suggests that interference ripples are the commonest at all localities. At most localities asymmetrical form-concordant ripples are next in abundance, followed by symmetrical wave ripples. The exception to this is on the Fleet shore between Rodden Hive Point and Abbotsbury Swannery, where symmetrical wave ripples are extremely common. This is also the area in which trace fossil diversity is greatest.



Fig.38. Facies 5. Graded sandstones overlying Facies 15 linsen bedded sands, Watton Cliff, West Bay. Note the 'in-phase' stacking of sand linsen in the bottom left of photograph.



Fig.39. Facies 19. Low angle cross-laminated sands, West Hill, Sherborne.



Fig.40 Top surface of low angle cross-laminated sandstone shown in fig.39 Note the coarse shell debris in the shallow channel to the left of centre.



Fig.41 Oblique Rhizocorallium and drainage channel edge, top surface of low angle cross-laminated sandstone, West Hill, Sherborne. Note the very steep sides of the channel, suggestive of a subaerial rather than submarine origin.

Though there may be some connection between trace fossils diversity and wave ripples, I suspect that both trace fossils and wave rippled slabs are collected less here than at other localities because of the tightly restricted access to the part of the Fleet shore owned by the Swannery.

It seems clear that the facies was strongly influenced by wave action and thus was deposited above wave base. This is quite compatible with the deposition of marl interbeds as the deposition of mud in environments affected by wave activity is controlled principally by three factors; wave activity, current velocity and suspended sediment concentration. Finegrained sediments and sands may be deposited under the same conditions of current velocity and wave activity, the latter being deposited under different conditions of suspended sediment load. Equally, if there is a temporary lowering of the level of wave activity, such as is common on a day to day basis due to variation in weather conditions, suspended mud may be deposited (McCave, 1971, p.95).

Some evidence suggests that this facies may have been deposited in very shallow water and may have occasionally been emergent. A single mudcracked specimen has been collected from Rodden Hive Point (SY 607804), though whether this was produced by subaerial shrinkage or syneresis is unknown. Secondly, outside the study area, vertebrate quadruped footprints have been recorded from the facies (Sarjeant, 1974). Small, possibly lacertoid footprints are present in Yorkshire Museum (specimen numbers Y.M. 870 and 871) labelled as from Sutton, Wilts. Sutton, one of the commonest of English place names, may refer to Sutton Benger. These tracks are superimposed on symmetrical wave ripples. It seems certain that these tracks are subaerial in origin.

It has been suggested (Sarjeant, 1974) that these footprints are the specimens described by George Poulett Scrope (1831) "from the forest marble beds north of Bath". Some of these are figured by Buckland (1837), who states that his figured specimens went to the Geological Society of London. Slabs of Forest Marble with footprints collected by G.P. Scrope are present in the Institute of Geological Sciences Museum Reserve Collection (Geol. Soc. Coll. 3365 - 3384) and are said to be from the neighbourhood of Castlecombe. It seems probable that the Yorkshire Museum specimens may originally have formed part of the same collection and have been split up by Scrope.

Other tracks from the facies are present in Oxford Museum: these have been ascribed to Limulids.

However, indications of emergence in the study area are very limited and it must be emphasised that it is unlikely that the sediment surface was frequently emergent.

Facies 5. Graded sandstones and bioclastic limestones

The majority of sections in the Association contain developments of this facies. Characteristically it is represented by sharp-based sandstones up to 10cm. thick with a shell or marl intraclast lag at the base and a rippled top. These are usually bioturbated, with an ichnofauna including Imbrichnus wattonensis Hallam, Pelecypodichnus, Gyrochorte comosa Heer, Thalassinoides, Neonereites, Monocraterion, Planolites, Palaeophycus, Tibikoia and Teichichnus as well as a variety of indeterminate surface trails. The sandstones occur interbedded with sands and marls of facies 1, 2 and 15.

Facies 16. Ripple cross-laminated sandstone

Beds of ripple cross-laminated sandstones 10 to 60cm. thick, are common in the inland outcrops but do not occur on the Dorset

coast. For example, in stream sections at Corscombe and Cogley Wood and at Sutton Bingham Reservoir, such sands constitute an important part of the sequence in the Association. Some such sands at Cogley Wood are clearly rippled at the base and top but diagenesis seems to have obscured the ripples in the centre of the beds.

Ripple form is not usually distinguishable in section but in plan interference ripples may occasionally be made out.

The trace fossil assemblage in this facies is more restricted than in interbedded sands and marls; only Gyrochorte and non-branching burrows are common.

Facies 17. Structureless sandstone

Calcite cemented fine- and medium-grained quartz sandstone with no sedimentary structures is common in Association D. It occurs in sections at West Hill, Sherborne, Hinton Charterhouse (ST 772573) and Beckington (ST 800516). Original sedimentary structures have probably been obliterated by diagenesis. This has certainly happened at Hinton Charterhouse (ST 772573) where parallel lamination is preserved in concretions whilst at the same horizon no structures are present in loosely cemented sands.

Facies 18. Mud Flake Conglomerates

Grain supported mud flake conglomerates in a fine sandstone matrix are present only in the section near Hinton Charterhouse; the type section of the Hinton Sands of William Smith and subsequent authors (ST 772573).

The beds have erosional bases and are up to 75cm. thick. The majority of mud clasts are about 15mm long, 3mm. thick and are flat in profile. Occasional large clasts of closely interbedded very fine sandstone and marl up to 150mm long and 80mm. thick occur. In some cases the clasts are obliquely imbricated.

Small lenses with flat tops and convex bases occur towards the base of the section but the majority of horizons are continuous across the exposed face of the quarry, i.e. > 30m in lateral extent.

Interpretation

The source of mud clasts is probably from a closely interbedded sequence of fine sands and marls. At least some of the smaller lenses are channel lags and the erosional bases of the other horizons suggest a channel origin. The opposed imbrication of mud clasts in two of the beds suggests that channels may have been cut from two diametrically opposed directions.

Facies 19. Low angle cross-laminated sands.

Well sorted fine to medium grained sandstones characterised by the dominance of a low angle, tabular cross-lamination dipping at an angle of $2 - 4^{\circ}$ are recorded from only one locality; West Hill, Sherborne (ST 642147), (Fig.39).

The sand body in which the cross-lamination is present is up to 90cm. thick. It overlies lenticularly bedded sands and marls with abundant finely comminuted plant debris and has a slightly erosive base. Approximately 20cm. above the base is a parting accentuated by the presence of shell debris which separates an apparently structureless lower bed from the cross-laminated horizon. This contains Modiolus sp. and ? Quenstedtia and is bioturbated by oblique Rhizocorallium, (Fig.41). The top surface of the sand body is covered with wave ripples and also shows oblique Rhizocorallium up to 9cm. in length. It is cut by a broad shallow channel up to 50cm. wide and 2 - 4cm. deep with very steep sides which is filled with shell debris. In places this shell debris spills out of the channel over the surrounding rippled surface, truncating ripple crests for a few centimetres either side, see figures 40, 41.

The wave ripple crests run parallel to the direction of dip of the low angle cross-lamination and at 90 degrees to the axis of the channel.

Interpretation

The very low angle cross-lamination may be compared with that produced in Recent shoreface and upper foreshore environments. In foreshore facies the dominant sedimentary structure is parallel lamination dipping gently seaward at 2 - 3 degrees (Hoyt and Weimar, 1963). Laminations comprise distinctive two-fold couplets 1 - 2cm thick or less composed of a finegrained or heavy mineral layer overlain by a coarse grained or light mineral layer (Clifton, 1969). The laminations are produced by swash and backwash of waves.

The upper shoreface, which commences at low tide level and terminates at fair weather wave base has as its predominant sedimentary structure low angle cross-lamination dipping seawards at slopes of between 1:10 and 1:200 (Elliott, 1978).

The shoreface may contain strongly bioturbated structureless horizons as well as cross-lamination. The relative importance of these two lithotypes depends on the importance of wave effects. If low wave energy conditions are normal, biogenic structures have a higher preservation potential and may be relatively more important. At this locality, well preserved trace fossils are present at two horizons and structureless sands are present at the base of the sand body.

It seems likely that the top of the sand body was at times emergent as it is cut by a channel which appears, on the grounds that it has very steep sides incompatible with a submarine origin, to be a drainage channel. The presence of oblique Rhizocorallium on the top surface suggests that it was at times submergent and thus

that the sand body was probably intertidal.

The sedimentological setting of the sand body suggests that it probably represents a small bar rather than an attached beach as it is underlain by linsen bedded sands and overlain by marls and sand-streaked marls thought to be of off-shore origin. The marls above the sand body contain selenite which probably originated during weathering.

Some 3m. above the sand body in the section are autochthonous macrofaunas which probably thrived in lower energy conditions than those which prevailed when the sand body was deposited, see pp. 161-163.

Oblique Rhizocorallium occurs in shallower water conditions than its horizontal equivalent (Ager and Wallace, 1970; Farrow, 1966). In the study area all the Rhizocorallium found in Association D, with the exception of one specimen from Watton Cliff, are oblique, whereas both specimens found in Association A are horizontal.

As pointed out by Farrow (1966) aligned burrow building in decapod crustacea (such as are thought to have produced Rhizocorallium) cannot easily be explained without invoking tidal currents as a modus operandi: "It is in consequence reasonable to infer that where the Jurassic burrows are strongly aligned, the rocks in which they occur were deposited inter-tidally, or at least within the influence of tidal flux. Correspondingly, where the ethological pattern of the same genera is random it is probable that the enclosing sediments lay in deeper water below the level of the lowest tides..." (Farrow, 1966, p.146). The orientation of all specimens on the top surface of the sand body at West Hill was measured. The bearings of lines parallel to the length of the traces are shown in figure 42.

This clearly shows that they are not preferentially oriented. However, I still consider that the top of the sand body was intertidal on sedimentological grounds.

ORIENTATION OF OBLIQUE RHIZOCORALLIUM, WEST HILL,
SHERBORNE.

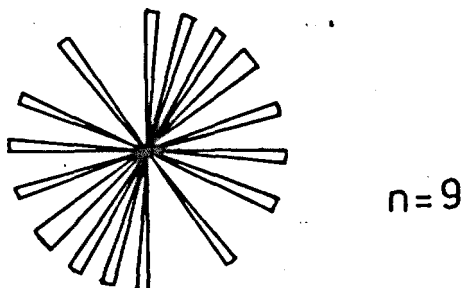


Fig. 42 Orientation of oblique Rhizocorallium on the top surface
of sand shoal, West Hill, Sherborne.

Faunas in the facies association

Oyster lumachelles

The lumachelles are composed of a matrix of marl, silt and small quantities of very fine sand in which occur large, in situ accumulations of oysters and other faunal elements, mainly brachiopods and bivalve molluscs.

Poor exposure has prevented any detailed examination of the finegrained sediments; only one substantial lumachelle is present in the study area, at Witham Friary (ST 746416). This is exposed in field brash and in the banks of the lane leading east from Seat Hill to Witham Friary.

The presence of pelleted marl in the sediment fill of articulated brachiopods suggests that much of the sediment may originally have been pelleted. Pellets are usually small, between 0.5mm. and 1.5mm. long, and may have been bivalve pseudofaeces. Comparable pellets occur in facies association B and in oyster reefs in the Hampen Marly Formation of the Great Oolite Group (Palmer, 1979).

The thickness of the lumachelle at Witham Friary is between 2 and 3m. It is at least 40m in length and contains lenses or interbeds of finegrained sediments. The topography of the lumachelle is not clear, as is usually the case with Bathonian oyster reefs in this country (Hudson and Palmer, 1976).

Bivalve fragments are usually disarticulated, though rare articulated Praeexogyra hebridica are present, and many articulated brachiopods are found. The latter are usually crushed. The fauna is listed below:

? Bakevillia sp.

Camptonectes laminatus

Praeexogyra hebridica

Lopha gregarea

Placunopsis socialis

Kallirhynchia concinna

Epithyris sp.

Dorsoserpula sp.

Stomatopora sp.

Nubeculinella sp.

The vast majority of the assemblage is composed of P. hebridica valves, many of which have large attachment areas and grew on other individuals of the same species. They are noticeably better preserved than the oysters in association C. The largest specimens are up to 7cm in length and frequently show xenomorphism in the early growth stages.

Lopha gregarea, Bakevillia sp., Placunopsis socialis and Epithyris sp. are all uncommon and Kallirhynchia concinna is the second most abundant taxon, excluding the serpulids. Most growth stages of K. concinna between the mature width of approximately 3cm. and approximately 1cm. are present. The smallest individuals bear more resemblance to K. expansa (S.S. Buckman). This may have implications for the taxonomy of the genus as it seems likely that both Buckman's species may be simply variants of the same Linnaean species and thus represent different stages in an allometric pattern of growth.

Both Lopha gregarea and P. hebridica are encrusted by Dorsoserpula sp. and rarely by Stomatopora sp. The encrusting foram Nubeculinella is present on approximately 15% of oysters.

A second small development of an apparently very similar fauna occurs on the west side of the road cutting 20m south of the lodge near Westfield Farm, North Coker (ST 534128). Here P. hebridica, Dorsoserpula sp. and K. concinna have been recorded. Exposure is

very poor and the dimensions of the fossiliferous horizon could not be established.

Both the lumachelles occur very high in the succession; the base of the one at Witham Friary is approximately 4 - 5m below the base of the Cornbrash, whereas that at North Coker is only about 2m below it.

Interpretation

P. hebridica - dominated lumachelles are not uncommon in the British Bathonian, occurring in particular in the Great Estuarine Series of the Inner Hebrides, in the Hampen Marly Formation, in the Cotswolds and in the Fuller's Earth on the Dorset coast.

The fauna of the Forest Marble lumachelles compares most closely with the reefs in the Hampen Marly Formation. This is part of the Great Oolite Group which occurs beneath the White Limestone Formation in the Oxford district and appears to pass laterally into it in the area around Cirencester.

At Milton Quarry (c.SP 4535) marls with abundant P. hebridica and rarer K. concinna developed as lumachelles up to 2m. in thickness are present (Richardson, 1933; Palmer, 1979). With the exception of occasional encrusters such as Dorsoserpula, ectoprocts and foraminifera, other species are not common and, where present, are not determinable due to preferential leaching of aragonite. It has been suggested that the solution of aragonitic taxa has biased the composition of the assemblage to the extent that it gives the false impression that the two species dominated the assemblage when the rocks were laid down (Palmer, 1979, p.198). However, this does not appear to have been the case in the Forest Marble in the study area, where more species are preserved in the lumachelles, though it is clear that some leaching of aragonite has taken place as steinkerns

of heterodonts are present.

Despite the problem of diagenetic leaching, the assemblages in the Hampen Marly Formation and the upper part of the Forest Marble are strikingly similar. The Hampen Marly Formation reefs are thought to have developed in quiet conditions, not greatly influenced by currents, in a setting between brackish water lagoons developed to the north and north-east around the Anglo-Belgian Landmass and an off-shore region to the south-west (Palmer, 1978). The similarity of the faunas suggests that those of the Forest Marble may have originated in similar quiet, very shallow water conditions.

P. hebridica has been compared with Recent Crassostrea (Hudson and Palmer, 1976). This genus develops reefs in very shallow water in the Texas coast lagoons (Parker, 1960). At the present day oyster reefs in general develop best in water depths of 1 to 10m. (Stenzel, 1971).

P. hebridica is a euryhaline species (Hudson and Palmer, 1976). It occurs in association with K. concinna in the Lower Ostrea Beds of the Great Estuarine Series which are deposits of less than fully marine salinity containing no cephalopods, bryozoans, corals or brachiopods, apart from K. concinna. This suggests that K. concinna was probably also tolerant of somewhat reduced salinity.

The presence of ectoprocts and another brachiopod species in the Forest Marble Formation lumachelles is suggestive of fully marine salinities, though echinoid spines, which are present in the Fuller's Earth lumachelle, are not found. Foraminifera are very common in the Fuller's Earth lumachelle but relatively uncommon in the Forest Marble assemblages.

Other faunas in the facies association

The only other substantial faunal development found by myself in situ in the facies association also occurs immediately below the Cornbrash. It is present on the north side of a road cutting on the association at West Hill, Sherborne (ST 642147). Its components are:

Palaeonucula waltoni

'Cidaris' sp.

Modiolus imbricatus

Isognomon cf. isognomonoides

Cycloserpula sp.

Costigervillia crassicosta

Serpula intestinalis

Camptonectes laminatus

Dorsoserpula sp.

Camptonectes annulatus

Stomatopora sp.

Protocardia sp.

Praeexogyra hebridica

Protocardia sp. has been found in loose blocks of impure micrite on which Cycloserpula is present. Palaeonucula waltoni has only been found as loose valves ex situ.

The remainder of the shell debris clearly forms a taphocoenosis as it may be seen to be imbricated in section. However it is not likely to be a significantly transported assemblage as articulated Costigervillia crassicosta are common.

Beneath the imbricated lenses of shell debris there appear to be thin patchy developments of micrite, though the details of the section have been comprehensively obscured by regrading and this cannot be clearly demonstrated.

The fauna can be divided into five main categories: shallow burrowing sluggish infaunal bivalves are represented by P. waltoni and Protocardia sp., semi-infaunal bivalves by Modiolus imbricatus, bysally attached Bivalves by Costigervillia crassicosta, Camptonectes and

Isognomon cf. isognomonoides, encrusters and cementing bivalves by serpulids, ectoprocts and P. hebridica, and vagile browsers by 'Cidaris' sp.

The strongly inequivalve Isognomon isognomonoides and Costigervillia crassicosta may have been closely adpressed to the substratum (cf. Stanley, 1970) or possibly fissure-dwelling.

The impure micrite may have formed a suitable attachment site for bysally attached bivalves or alternatively attachment sites may have been provided initially by semi-infaunal bivalve shells or by other shell fragments. In this respect the establishment of the assemblage bears a certain resemblance to that of the oyster/Kalli-rhynchia assemblage of the Hampen Marly Beds (Palmer, 1979) but the fauna itself differs considerably. Similar assemblages have not apparently been recorded previously from the English Bathonian.

The fauna reported from the road cutting opposite Wick Farm, Farleigh Hungerford (Cox and Arkell, 1948 - 1950) has not been found at outcrop. The road cutting, now presumably much widened, is heavily regraded and only a single Praeexogyra hebridica valve was collected. Cox and Arkell (1948 - 1950) state that "Walton's 'Forest Marble' fossils (from Farleigh Hungerford and Lacock) communicated to Lycett ... include the principal species of the Bladon Beds (Upper White Limestone) of South Oxfordshire but the road cutting opposite Wick Farmhouse, Farleigh Hungerford (Lycett, 1863, p.118) is in Upper Forest Marble, not more than 20 feet below the Cornbrash".

The lithology of this fossiliferous horizon is described by Walton (in Lycett, 1863, p.118) as a "crumbly, shelly marl".

Species recorded by Cox and Arkell from this locality include:

<u>Palaeonucula variabilis</u>	<u>Anisocardia truncata</u>
<u>Palaeonucula waltoni</u>	<u>Tancredia marmorea</u>
<u>Eonavicula gibbosa</u>	<u>Protocardia stricklandi</u>
^a <u>Girvillella ovata</u>	<u>Corbula hulliana</u>
^a <u>Girvillella monotis</u>	<u>Ataphrus comma</u>
<u>Isognomon isognomonoides</u>	<u>Amberleya bathonica</u>
<u>Plesiopecten subspinosus</u>	<u>Neritopsis guerrei</u>
<u>Exogyra crassa</u>	<u>Lissochilus buvignieri</u>
<u>Lopha marshi</u>	<u>Lissochilus bicinctus</u>
<u>Astarte (Coelastarte) compressiuscula</u>	<u>Neridomus cooksoni</u>
<u>Eomiodon fimbriata</u>	<u>Piettia denticulata</u>
<u>Anisocardia loweana</u>	<u>Ampullospira subtexta</u>
<u>Anisocardia davidsoni</u>	<u>Cylindrobullina suessa</u>

Loose blocks dumped in the stream section at Farleigh Hungerford (ST 786573) from an unknown locality may be from this horizon. A highly fossiliferous grey marl with numerous shell fragments and disarticulated valves of Anisocardia davidsoni, Palaeonucula variabilis, Astarte (Coelastarte) compressiuscula and Modiolus imbricatus is found in lumps up to 35cm thick.

If these loose blocks are from the same horizon as Walton's fauna, they represent a much more diverse fauna than is common in the facies association. This may be because the fauna includes bivalves from several different habitats. These include shallow infaunal burrowers (Palaeonucula, Astarte (Coelastarte), Eomiodon, Anisocardia, Protocardia, Corbula and Tancredia), epifaunal adpressed byssate forms (Eonavicula, Girvillella, Isognomon, Plesiopecten) and cemented epifaunal types (Exogyra and Lopha) as well as the semi-infaunal Modiolus.

A similar but less diverse fauna is characteristic of the Aphanoptyxis bladenensis bed of the White Limestone Formation in the Cotswolds. Apart from Aphanoptyxis bladenensis, which normally dominates the fauna, Modiolus imbricatus, Eomiodon fimbriatus, Bakevillia waltoni, Corbula hulliana, Protocardia stricklandi and Protocardia lycetti are common associated species (Barker, 1976). In the Wiggold Railway Cutting north-east of Cirencester, as in the loose blocks found in this stream section, A. bladenensis is apparently absent but the unique lithological nature of this bed and its associated fauna leaves no doubt as to its identity (Richardson, 1933, p.62). The A. bladenensis bed invariably shows a grading from a very coarse intrasparite at the base to a very fine micritic sub-lithographic limestone at the top. At Wiggold Railway Cutting a hardground is developed at the top of the bed (Barker, 1976, p.1:50). Barker (op. cit.) suggests a close relationship between substrate and fauna for this horizon, arguing that some degree of substrate stabilisation was required for development of this fauna.

Barker (1976) and Palmer and Jenkyns (1975) agree that this bed was deposited in very shallow water conditions and that in places it was emergent, though not in the Cirencester area.

The lithological differences between the A. bladenensis bed and the loose blocks found in the stream section at Farleigh Hungerford may partly explain the differences in the faunas of the two horizons.

The road cutting in which the fauna was recorded by Walton (in Lycett, 1863) is above the main sand body in the facies association (=Hinton Sands) in the vicinity of Wick Farm, Farleigh Hungerford.

Trace fossils of the facies association

Previous work

The earliest observations of the trace fossils in the facies association were those of Scrope (1831), see p.151. Apart from this record of footprints and winding trails, the assemblage was mentioned by Woodward (1894) and has been described at one locality by Hallam (1970) and in the area around Bath by Penn and Wyatt (1979).

Hallam described the ichnofauna at Watton Cliff (SY 453908). He recorded Gyrochorte comosa Heer, Pelecypodichnus, ?Palaeophycus, Planolites and Imbrichnus wattonensis. He suggested that the clastic sediments of the Forest Marble Formation may have been deposited under conditions of slightly less than fully marine salinity as shallow marine deposits in the British Jurassic usually contain an abundance of Diplocraterion, Chondrites, Rhizocorallium and Thalassinoides.

Penn and Wyatt record the following ichnofauna from the facies association in boreholes in the Bath area:

indeterminate burrows and horizontal trails

Gyrochorte comosa.

They point out that G. comosa has been regarded as an intertidal trail.

The trace fossil assemblage

In the association as a whole the following assemblage is present:

Gyrochorte comosa Heer

Imbrichnus wattonensis Hallam

Pelecypodichnus Seilacher

Neonereites Seilacher

Tibikoia Hatai, Kotaka and Noda

Rhizocorallium Zenker



Fig.43. Gyrochorte comosa Heer. Positive epirelief on upper surface of sandstone lens



5cm

Fig.44 Underside of the same block. Note that the negative hyporelief is less sinuous than the positive epirelief.

Monocraterion Torrell

Planolites Nicholson

? Palaeophycus Hall

Teichichnus Seilacher

? Thalassinoides Ehrenberg

Burrows of uncertain ichnogenus.

Gyrochorte comosa Heer

Descriptions of the ichnogenus Gyrochorte have been given by Weiss (1940), Seilacher (1953) and Heinberg (1973) and of the ichnospecies by Hallam (1970).

The trace itself is composed of a positive epirelief on the top surfaces of sandstone blocks and a negative hyporelief on bottom surfaces, see figures 43, 44. The epirelief consists of a winding braided bilobate trail up to 4mm wide. The braided bilobate hyporelief may occasionally be seen to pass into a smooth or slightly raised cylinder of sediment which presumably represents a burrow.

Gyrochorte has been interpreted as the trace produced by a burrowing worm-like organism with the anterior part of its body raised above the rest of the animal (Seilacher, 1953; Heinberg, 1973). According to this interpretation the animal may have moved along approximately horizontally within the sediment with its head raised and moving from side to side to search for food.

Hallam felt unable to support the claim of Weiss (1940) and Seilacher (1953) that this was the mode of origin of the trace, for two reasons. Firstly he suggested that where two epireliefs cross, the topographically higher ridge was the older one and that it had been simply raised up by the younger ridge and thus that it must be produced by a simple burrowing process taking place very

close to the sediment surface, which simply raised a bilobate braided ridge on the sandstone surface. Secondly he could not support Weiss's claim that Gyrochorte ridges show a sinusoidal oscillation with respect to the underlying grooves.

The normal interpretation of the crossing points of two epireliefs is that the 'topographically higher' ridge is the younger one. The reason that it appears to be higher is that it cross-cuts the 'lower' older ridge. Thus the trace must be produced by an animal with at least part of its body raised above the burrow and hyporelief, this part cutting across previous bioturbation structures. Examination of Hallam's material suggests that it does not contradict this interpretation. The sinusoidal oscillation of the epirelief relative to the hyporelief, which indicates that the Gyrochorte organism moved its anterior from side to side may be demonstrated in material from Watton Cliff which shows that the epirelief is a much more complex trace than the smoothly curving hyporelief (Figs. 43, 44).

Examination of Heinberg's material suggests that it is of a different ichnospecies at least, being very much larger - up to 1cm. in width - and with a vertical separation between epirelief and hyporelief of up to 15cm. No burrows were seen beneath the hyporelief..

In G. comosa from the Forest Marble the maximum vertical separation that has been observed between epirelief and hyporelief is 1.2cm. and a separation of more than 5mm is very rare and thus significant raising of the anterior part of the body may not have been a common aspect of behaviour of the trace-producing organism.

Seilacher (1953) states that Gyrochorte is an ubiquitous form occurring in flysch as well as in shallow marine sediments, though

it is considerably smaller in flysch. It occurs in the Callovian and Oxfordian of Yorkshire and in the Hettangian of Lower Saxony (Hantzschel and Reineck, 1968) in apparently shallow marine conditions. Gyrochorte carbonaria, which is certainly no true Gyrochorte (Hantzschel, 1975) is abundant in the non-marine, low salinity portions of the Carboniferous cycles in the Ruhr (Hallam, 1970). It may also occur in intertidal environments.

Thus the majority of occurrences indicate that Gyrochorte cannot be regarded as a good indicator of any narrowly defined environment and that true Gyrochorte may not have been identified in any sediments considered to have been deposited in low salinity conditions.

Imbrichnus wattonensis Hallam 1970

This ichnospecies has been fully described by Hallam (1970, p.197, pls. 2b, c). The interpretation of Bandel (1967) and Hallam (1970) that it is produced by movement of small bivalves through the sediment is supported. Figure shows a specimen of Imbrichnus wattonensis photographed at Watton Cliff with Pelecypodichnus at one end of the trail. Imbrichnus has also been found associated with Pelecypodichnus in the Carboniferous of Kansas (Bandel, 1967).

Pelecypodichnus Seilacher 1953

The priority of Lockeia as the name of this ichnogenus has now been overruled and it has been declared nom. obit. under the 50 year I.C.Z.N. rule.

Specimens up to 1.5cm in length are common in the facies association. Following Seilacher (1953) they are interpreted as the resting traces of small bivalves. Associated body fossils have not been found.

Many occurrences of this ichnogenus are in deposits of less than

fully marine salinity. For example, in the British Bathonian it occurs in the Great Estuarine Series of Trotternish, Isle of Skye. It is also common in the British Coal Measures in 'non-marine' environments (Eagar, 1974) and in the Rhaeto-Lias Coal Measures of Sweden (Hallam, 1974). However, it also appears to be widespread in fully marine conditions, e.g. in Eocene flysch (Crimes, 1977) 'paralic' Pennsylvanian sediments (Hakes, 1977) and in the top of the Trenton Group (Middle Ordovician of the U.S.A.), (Osgood, 1970). Pelecypodichnus has only been observed on the bases of sand beds in the facies association. There is no evidence of vertical migration in response to sudden influx of sediment or an overall fast sedimentation rate as noted by Eagar (1974).

Neonereites uniserialis Seilacher 1953

This is interpreted as a postdepositional internal burrow and may be the counterpart of Helminthoidea labyrinthica in a sandy environment (Seilacher, 1962). Helminthoidea has not been recorded from the Forest Marble Formation. The Forest Marble specimens of N. uniserialis are usually poorly preserved, see figure 45.

Tibikoia

Following Hatai, Kotaka and Noda (1970), small rod-like moulds up to 2.5mm long and 0.5mm wide occurring in clusters on the undersides of a thin sandstone lens are assigned to this ichnogenus. They occur in roughly concentric distributions and are interpreted as the moulds of faecal pellets deposited on the underlying muds. They are rare and only one occurrence is recorded.

Rhizocorallium Zenker 1836

Oblique Rhizocorallium up to 7cm in width are fairly common in the facies association, though rare at Watton Cliff. These traces are interpreted



Fig.45. Imbrichnus wattonensis Hallam, showing Pelecypodichnus at the end of Imbrichnus. Lower surface of sandstone block, Watton Cliff, West Bay.



Fig.46. Neonereites uniserialis Scilacher. Fleet Shore near Rodden Hive Point, Langton Herring, Dorset.

as the burrows of deposit-feeding animals. Small faecal pellets are frequently found associated with the trace, see figure 48.

Palaeoecology of Rhizocorallium

This ichnogenus is not common in deposits of reduced salinity but is abundant in shallow marine sediments in the European Jurassic, e.g. Ager and Wallace, 1970; Hallam, 1970. Oblique Rhizocorallium occurs in deposits thought to be shallower than those in which its horizontal counterpart is found (Farrow, 1966; Ager and Wallace, 1970). The former (see fig.48) is only recorded from facies association D of the Forest Marble in the study area.

Monocraterion Torrell 1870

Funnel shaped structures penetrated by straight vertical burrows occur on the bases of some sandstones. These are up to 27mm. in width and 25mm. in maximum diameter and can be assigned with confidence to Monocraterion, see figs.49,50.

Planolites Nicholson 1873

All horizontal, endogenic, non-branching burrows are assigned to this ichnogenus. Such burrows are extremely common in the facies association. The ichnogenus ranges from Cambrian to Recent and is cosmopolitan (Hantzschel, 1975).

? Palaeophycus Hall 1847

Smooth, sub-cylindrical branching sinuous sediment-filled tubes up to 2.5mm. wide were assigned to ? Palaeophycus by Hallam (1970) following Hall (1847).

Similar burrows are very common in the facies association, though some of these show bends in the direction of the burrows at almost 90° and appear similar to small parts of Palaeomeandron or Protopalaeodictyon (see Hantzschel, 1975, fig. 60, 56). These are illustrated in fig.5L



Fig.47. Horizontal Rhizocorallium, East Cranmore Railway Cutting, Somerset.

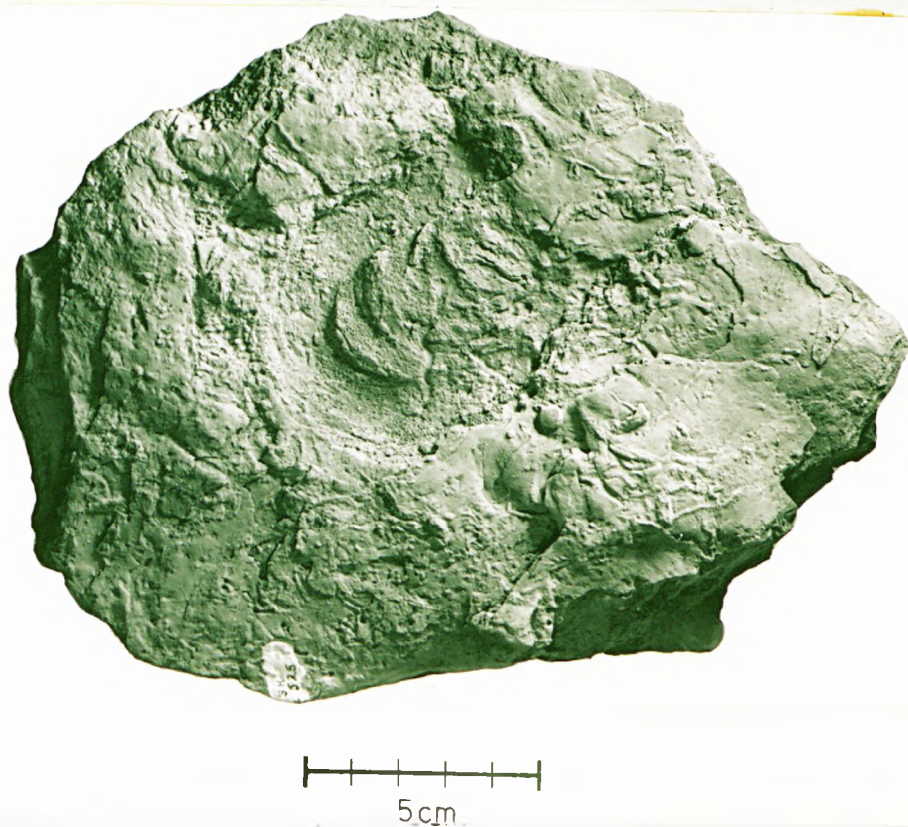


Fig.48. Oblique Rhizocorallium, Fleet Shore near Rodden Hive Point, Dorset.

Teichichnus Seilacher 1955

Typical vertically stacked spreite up to 15cm. in length occur sporadically throughout the facies association and are particularly common on the Fleet Shore near Herbury Promontory and Rodden Hive Point. Burrows transitional between Teichichnus and Thalassinoides are also common at these localities, see fig. 52. These are composed of typical branching subhorizontal burrows with some vertical and oblique tunnels, with horizontally stacked spreite at the base of the horizontal elements. These are very similar to Eocene burrows recorded by Hester and Pryor (1972), though the latter are transitional between Ophiomorpha and Teichichnus.

? Thalassinoides Ehrenberg 1944

Although no burrows clearly assignable to this ichnogenus have been found sufficiently well preserved to make a clear diagnosis, typical triple junctions of burrows with swellings at the junctions have been collected from Redlynch and East Cranmore Railway siding (ST 694434). The burrows are generally less than 1cm. in diameter and the junctions less than 1.5cm. in diameter.

Trace fossils of uncertain ichnogenus

Species 1. Fig. 53

The trace is 18cm. in length and up to 33mm. wide. It is composed of a series of connected v-shaped vertically retrusive 'spreiten' up to 1cm. in depth. The v-shaped elements are thinner at the apex than at the lateral extremities, where they terminate in lobate bulbous processes.

The trace is preserved on the upper sub-horizontal surface of a rippled sandstone block found on the Fleet Shore between Abbotsbury Swannery and Rodden Hive Point. It appears in part to follow the



Figs. 49 & 50. Monocraterion. Oblique view of underside of sandstone block, and elevation of same specimen.





5cm

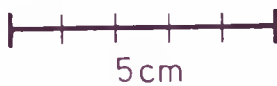
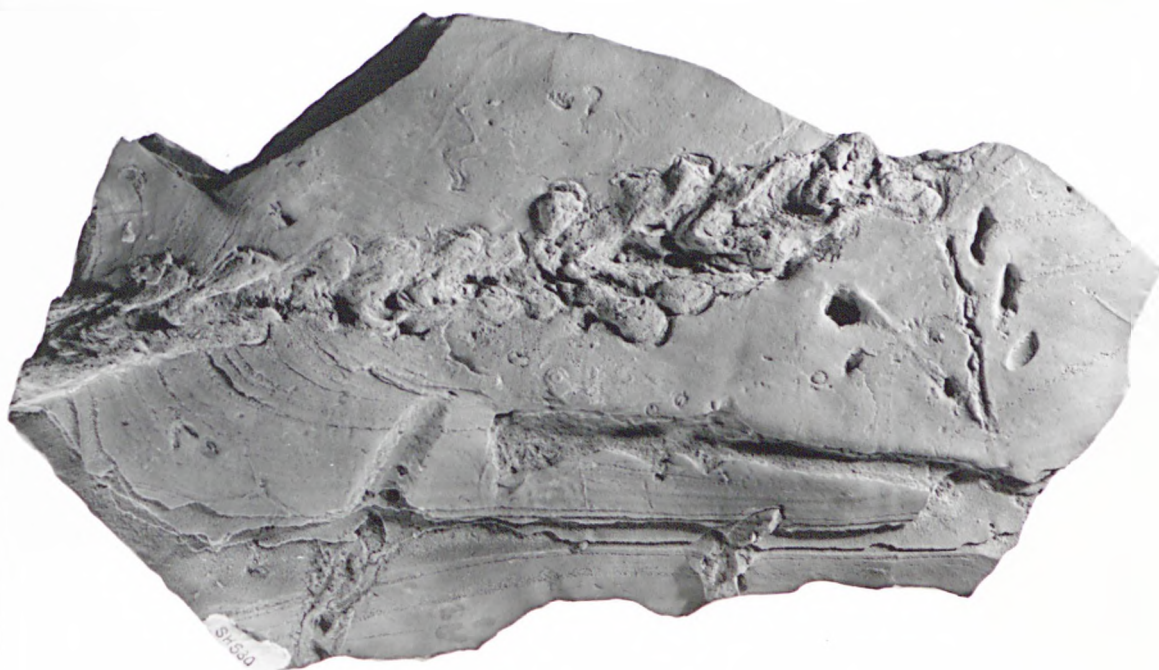
Fig.51. ? Palaeophycus Hall. Facies Association D East Cranmore
Railway Siding, Somerset.



5cm

Fig.52. Burrow transitional between Teichichnus and Thalassinoides,
Herbury Promontory, Langton Herring.

Fig.53. Trace fossils of uncertain ichnogenus spp. 1 and 2. Species 2 is on the right of the specimen. Facies Association D, Fleet Shore between Abbotsbury and Rodden Hive Point.



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contours of the rippled sandstone but at one end is clearly raised above the level of the surrounding sandstone. This suggests that the trace is post-depositional (endichnial) and was either formed at a sand/marl interface or re-exposed by penecontemporaneous erosion after preferential cementation of the trace.

The simplest interpretation of the formation of the trace would be that it was formed by the backward and downward movement of paired limbs or other processes in a manner similar to that employed when swimming the breast stroke. This would produce a locomotive trace in which the direction of movement was towards the apex of the v-shaped elements.

Species 2. Fig. 53.

This trace is 41mm. in length and 12mm. wide. It is composed of a straight furrow preserved as a negative epirelief accompanied by three oblique parallel furrows distributed at intervals of 10mm. 2 - 3mm. to one side of the straight furrow.

The mode of formation of this trace is unknown but it appears to closely follow the contours of the sandstone block, suggesting that it may be a surface trail. Similar traces with paired oblique parallel furrows attached to the central furrow (Caprionichnus steinvikensis Harland, 1978) have been interpreted as endichnial burrows in which the oblique furrows are produced by part of the organism probing the sediment. Bearing in mind the proposed endichnial origin of Species 1 found on the surface of the same block, an endichnial origin seems possible for the trace.

Species 3.

Oblique, scratch-marked burrows terminating in a circular lensoid cavity up to 14cm. in length are recorded from Herbury Promontory. The scratch-marks are suggestive of a crustacean origin.

Significance of the trace fossil assemblage

It is clear that the trace fossil assemblage is of greater diversity than envisaged by Hallam (1970), who suggested that the absence of Diplocraterion, Chondrites, Thalassinoides and Rhizocorallium might indicate conditions of slightly less than fully marine salinity.

Rhizocorallium is common in the facies association and Thalassinoides may be present. Chondrites and Diplocraterion are absent. The latter has normally been found in conditions affected by high wave energy in which erosion or burial of the top part of the burrow is commonplace (Goldring, 1972) or in intertidal environments (Ager and Wallace, 1970). Chondrites is normally recorded as mottling in shales or limestones and would not be easy to detect in natural exposures of Forest Marble marl-dominated facies and possibly also in the sandstones; where endogenic traces are seldom visible. However it has not been recorded either from borehole material or from limestones within the study area. It is absent from the shallow marine assemblages in the Jurassic of the Yorkshire coast (Farrow, 1966).

It seems possible therefore, that the absence of Diplocraterion may be controlled by factors such as depth or wave energy rather than salinity. The presence of oblique Rhizocorallium suggests that the assemblage as a whole was probably very shallow subtidal in origin, although oblique Rhizocorallium also occurs in intertidal settings in the Formation.

The majority of the trace fossils are thought to be of crustacean bivalve or vermiform origin. Surface trails are notably uncommon. This may reflect a scarcity of motile epibenthonic organisms.

Sequences in Association D

Exposure

Good sections in the facies association are limited. They occur at Watton Cliff (SY 455907), West Hill near Sherborne (ST 642147), East Cranmore Railway Cutting (ST 694434), Hinton Charterhouse (ST 772573) and Redlynch (ST 697333). These are supplemented by temporary exposures at Holton (ST 691276) and Beckington (ST 800516) and stream sections at Meerhay (ST 484026), Chilcombe (SY 519917) Cogley Wood (ST 515070) and Hinton Charterhouse (ST 786573). Coastal sections on the Fleet Shore between Rodden Hive Point and Abbotsbury and on Herbury Promontory are rather discontinuous and slumped but give a good idea of the lithologies. Small sections in the Association are common where it overlies Association C in many inland quarries.

Sequential organisation of facies

All the sections on the Dorset coast, and the East Cranmore section are composed entirely of lenticularly-bedded sands and graded sandstones of facies 15 and 5 set in a matrix of marl or silt and sand streaked marl, see figures 13, 19, 36 and 14.

All these sections, and all the others examined, overlie calcirudites of Association C and in all cases the junction between the facies associations is gradational and interfingering. At Watton Cliff for example, calcirudites and calcarenite lenses are interbedded with quartz sand lenses and laminae for approximately 1m. at the base of the sequence (Fig. 36).

Thin graded sandstones, interpreted as storm deposits, appear to be randomly distributed in these sequences, though this has not been tested statistically.

The coastal sections do not show any vertical changes which

could be clearly interpreted as indicative of changes in the depositional environment on more than a local scale. The section at Watton Cliff does show intervals which are dominated by marls or sands but these cannot be clearly related to other sections and may thus reflect local variations in depositional environmental factors such as weather and suspended sediment load rather than any change in, for example, depth of deposition.

The distribution of finely divided macerated plant material in the coastal sections is not clearly related to position in the vertical succession. It is mostly found in ripple troughs and as laminae on tops of sand lenses and streaks and in bioturbation structures. At Watton Cliff the draping of sand streaks with such material is striking and may have resulted from storms washing out fine plant debris from coastal swamps. This debris would have become waterlogged and sank to form a drape on the storm sand deposit. The presence of charophytes and isolated non-marine ostracods, also presumably derived from land, suggests the relative proximity of a coastline.

In the coastal sections symmetrical wave ripples are much more common in the eastern exposures in the study area. In the western coastal sections interference ripples are the dominant type and unidirectional current ripples are common.

Moving inland the stream section at Meerhay (ST 484206) shows approximately 2m of slumped sand-streaked marls with abundant finely divided plant debris occurring 2.5m beneath undoubted Cornbrash marls. The intervening gap is unexposed. The sand body recorded by Wilson et al. (1958, p. 105) appears to be in the Cornbrash as it occurs above marls with Obovothyris spp. and Pholadomya deltoidea which undoubtedly belong to the Cornbrash Formation.

The stream section at Corscombe is clearly faulted and extensively slumped. Loose sand lenses and graded sandstones with symmetrical wave ripples are present in the association. In places somewhat reddened coarse calcirudite horizons up to 12cm. thick are present at intervals.

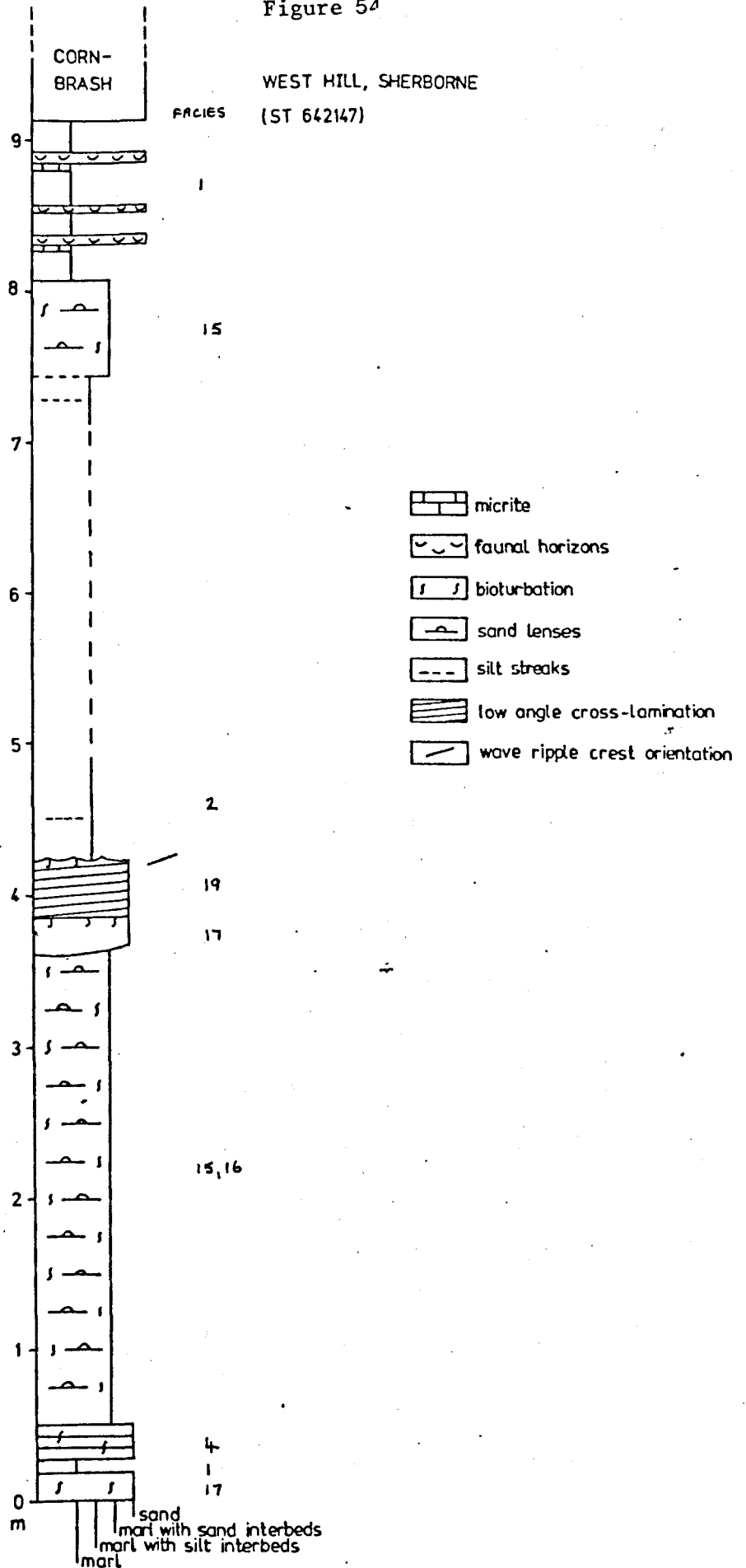
Further inland, at Cogley Wood (ST 515070), Sutton Bingham (ST 549114) and Birt's Hill (ST 514830), thicker sandstones occur in the facies association. At Cogely Wood the generalised succession below the Cornbrash is composed of linsen bedded sands with Gyrochorte and Rhizocorallium overlain by marls containing cosets of ripple cross-laminated sandstones and structureless sandstones up to 36cm. thick. Many of these ripples are form-discordant and on at least one top surface symmetrical wave ripples are present. No accurate assessment of the thickness of the succession could be made at this locality due to poor exposure.

At Sutton Bingham Reservoir no well exposed section is present, but at the reservoir boathouse, large rippled and structureless sandstone beds up to 59cm. thick are present on the lake shore. These have unidirectional current ripples on the surfaces showing a current direction of between 300° and 340° . They contain Gyrochorte and horizontal non-branching burrows and Praeexogyra hebridica fragments.

Poorly cemented yellow-brown sands at least 1.5m. thick occur in drainage ditches on Birt's Hill approximately 2 - 3m. below the Cornbrash. Similar loosely cemented sands are reported from the Thornford Pipe Trench at Honeycombe Wood, near Sherborne (Fowler, 1957). The section at West Hill, Sherborne, which is less than 2km. from Honeycombe Wood includes similar poorly cemented sands at the base of the exposed section. (see fig.54). Also towards the base of the section fine lignitic material is abundant and

Figure 5^d

WEST HILL, SHERBORNE
(ST 642147)



in places it imparts a clear lamination to marls and may completely cover bedding planes. The sand body in the centre of the section is interpreted as a small bar which was awash at least intermittently as shown by the presence of a drainage channel on its upper surface. Higher in the section are linsen bedded sands and sand-streaked marls with much finely macerated lignitic debris and rare authigenic zoned selenite crystals. The sulphate required to produce the selenite was presumably derived from sulphides produced by bacterial decay of the abundant organic debris in the sediments, cf. Siesser and Rogers (1976). These are in turn overlain by autochthonous bivalve-dominated faunas which probably developed on micritic substrates and which occur immediately beneath the Cornbrash.

If this section represents a regressive sequence, as is suggested by evidence from the Formation as a whole, the micrites, and subsequently the faunas, may have developed in an area protected behind the small bar.

The section exposed at West Hill differs considerably from that measured at the same locality by H.W.Bristow (Woodward, 1894, p.347).

In the Wincanton bypass cuttings near Holton (ST 691276) no thick sandstone horizons were recorded. The entire section of 4m., immediately beneath the Cornbrash, is composed of facies 1, 2, 5 and 15. Only poorly defined interference ripples were recorded.

At Redlynch (ST 697333) a development of the facies occurs less than 5m. above the Boueti Bed, at the base of the Forest Marble scarp, see fig.19. This is the only section in the facies association which does not occur at the top of the succession. Calcirudites overlie the facies towards the top of the scarp. However, in common with the other sections in the Association, it overlies calcirudites of Association C.

In the area north of Frome, thick sand bodies occur in the facies association. The best section through one of these is 1.2km. north of Norton St. Philip on the east side of the B3110 (ST 772573). The north face of this quarry was excavated by the Nature Conservancy Council in 1978 to a depth of about 8m. The section (fig. 55) shows finegrained parallel laminated sands and trough cross-bedded sands cut by channels containing a conglomerate with marl and laminated marl and sand intraclasts in a fine sand matrix.

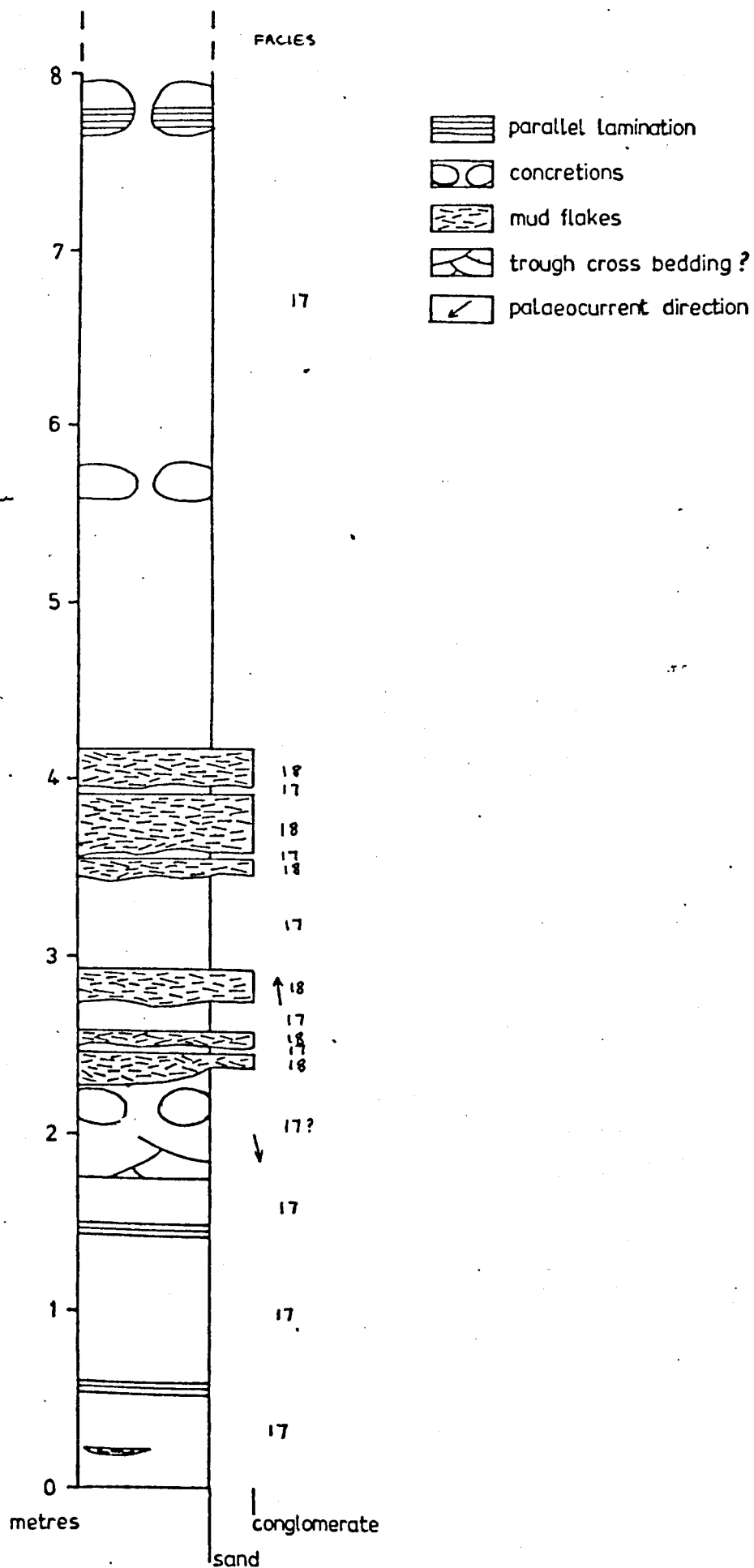
Mapping suggests that this sand body is continuous with that exposed in the stream section north of Wick Farm, Farleigh Hungerford, which crosses the A36 at ST 786573. The section here shows 2.5m of linsen-bedded sands with interference ripples and ripples with wave-straightened crests. Above these are at least 2.5m of marls with thin horizons of sand-streaked marl. This suggests that the major sand body in this area occurs about the middle of the succession in the Facies Association. Rare fragments of Girvillella sp., G. acuta and Placunopsis socialis have been recorded from the sand body.

At Beckington a temporary excavation for a garage extension at ST 800516 showed a section through a similar sand body. Loose blocks from the excavation exhibited vertical burrows with oolitic linings, Gyrochorte and fragments of Praeexogyra hebridica and Radulopecten vagans. Small channels up to 1m wide and 10cm deep with a sparse shell lag were also seen in loose blocks.

These sand bodies are the Hinton Sands of William Smith (1816) and subsequent authors. They are stated to be lensoid bodies of fine- to medium-grained quartz sand up to 10m thick which occur consistently just over half-way up the Forest Marble sequence (Penn and Wyatt, 1979, p.50). They also occur in the Rudge borehole and

Figure 55.

Section



similar sands, sometimes oolitic, occur in the Marston borehole.

Periam (1956) considered that mapping indicated that the sand bodies were elongate in shape.

The origin and nature of these sand bodies is unknown. However they occur in sequences which are considered to be very shallow marine in origin and they contain some marine fossils. No clear evidence of emergence has been found. The presence of internal channels filled with marl intraclasts suggests the possibility of washover processes operating and thus that the sands may be shallow marine shoals of some kind.

Depositional environments of Association D

The sedimentary structures in Facies 1, 2, 5, 15 and 16 suggest deposition in a shallow marine environment in which waves were the dominant source of energy but current influences were also present. It seems likely that many of the sand lenses and graded sandstones are storm deposits and consequently that exceptionally high energy events are likely to be relatively better represented in the rock record than the deposits laid down in fair weather conditions.

There are several independent, but rather sparse, indications that deposition took place in extremely shallow, occasionally emergent conditions. The record of mudcracks on the Fleet shore in the extreme south of the area and the vertebrate footprints recorded from Wiltshire in Facies 15 suggest the possibility of emergence. The postulated beach with its associated drainage channel at West Hill, Sherborne also probably indicates at least intermittent exposure.

Very shallow, probably quiet water conditions are indicated by the faunas. These all occur in the top 7m of the succession.

It is interesting to note that the faunas at West Hill, Sherborne and at Farleigh Hungerford occur sequentially above sand bodies and thus, if the general regressive tendency of the Formation as a whole is accepted, may have developed in protected conditions behind these sand bodies. Whether the faunas at Witham Friary and North Coker occur above the sand bodies is unknown.

The large quantities of comminuted plant debris found in the facies association suggest the proximity of land. It is probable that the lenses and laminae of plant debris result from fallout of material floating on the water surface, perhaps produced by severe storms.

The proximity of land is also suggested by the occurrence of rare charophytes and of occasional non-marine ostracods.

The dominance of eurytopic species in the faunas of the facies association suggest the possibility that the environment of deposition may have had somewhat restricted access to the open sea. However, species normally considered to be stenotopic do occur in the faunas and thus they cannot be considered to be typical of low salinity faunas. It seems more likely that a combination of various environmental stresses associated with very shallow water conditions may account for the notable absence of several taxa found elsewhere in the Formation, particularly in Association B. These would probably include variation in water temperature, salinity, depth and perhaps turbidity.

The distribution of sand in the association shows a very broad northwards increase in sand body thickness. No sand bodies more than 15cm thick are present on the Dorset Coast but inland there is an apparent gradational increase in maximum bed thickness. Beds up to 60cm thick are present at Corscombe and Sutton Bingham and

maximum thickness increases to about 90cm. at West Hill, Sherborne. Although this gradational increase cannot be upheld between Sherborne and Bruton, thick sand bodies are present in the boreholes around Frome, reaching a maximum thickness in the vicinity of Hinton Charterhouse and Farleigh Hungerford. It seems possible that this may reflect increasing proximity to a source of sand to the north of the outcrop.

Palaeocurrent data

The palaeocurrent data from the association is summarised in figure 56. The ripples from all facies have been divided into symmetrical and asymmetrical forms as it has not proved possible to separate with certainty asymmetrical wave ripples from asymmetrical current ripples.

Symmetrical (wave) ripple crest orientation is extremely variable even at a single locality, though this would be expected in very shallow marine conditions.

Asymmetrical ripples show a prominent bidirectional east-west or northwest-southeast orientation in the coastal sections suggesting the possibility of tidal influences. This is not clearly shown at other localities. At West Hill, Sherborne the beach sediments and associated drainage channel suggest an east-west elongated emergent sand bar with its beach sloping to the north-west.

It is clear from examination of the sections that the ripple orientations collected are only a very small proportion of the total number available, but the lensoid nature of most of the thin sands combined with the effects of slumping on the sections make accurate data very difficult to collect. Therefore it is probable that the palaeocurrent data obtained is not truly representative.

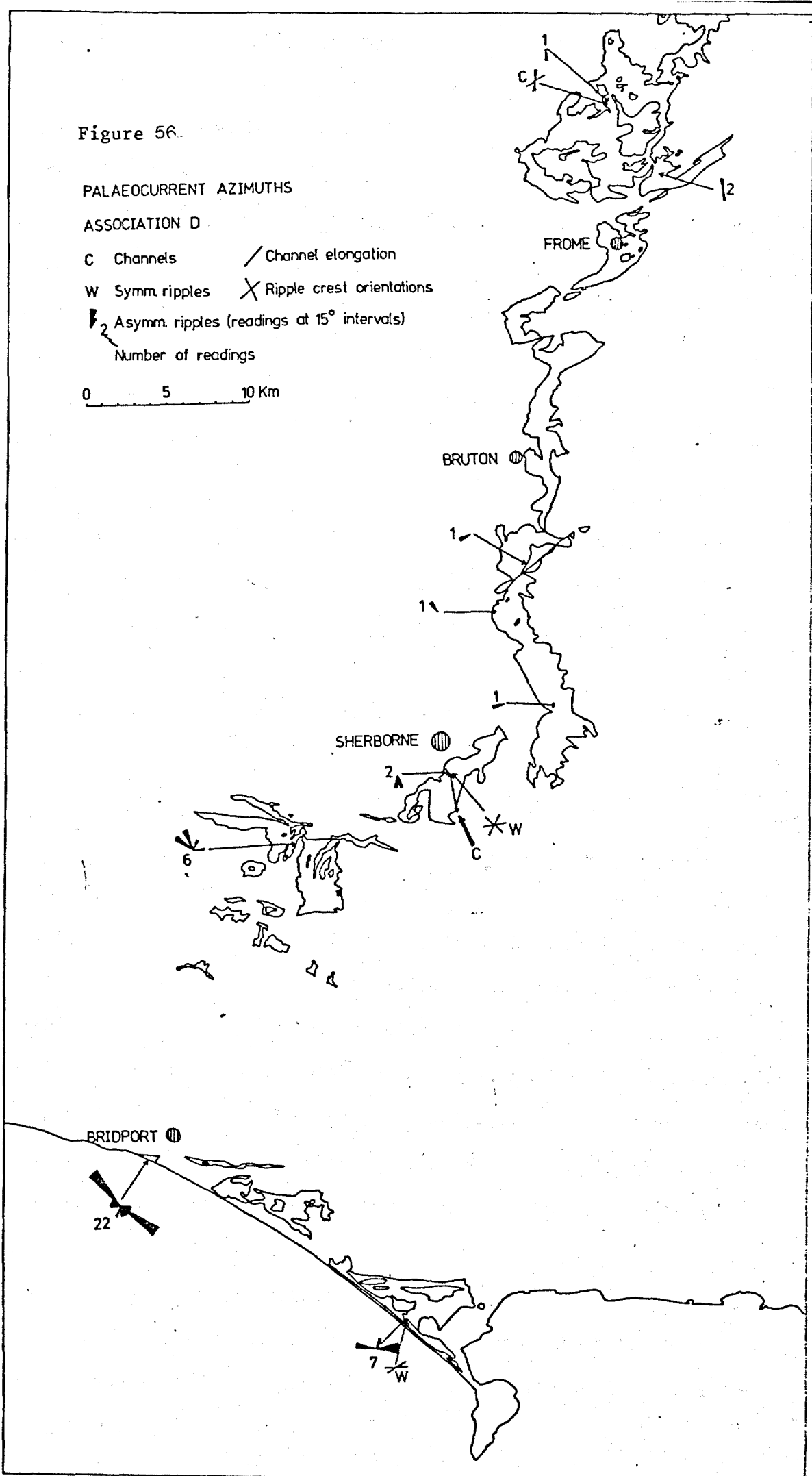
Figure 56.

PALAEOCURRENT AZIMUTHS

ASSOCIATION D

- C Channels / Channel elongation
W Symm. ripples X Ripple crest orientations
Asymm. ripples (readings at 15° intervals)
Number of readings

0 5 10 Km



CHAPTER SIX. DISTRIBUTION AND SEQUENTIAL ORGANISATION OF FACIES ASSOCIATIONS AND INTERPRETATION OF THE SUCCESSION.

6:1 Distribution of facies associations.

Four facies associations are present in the study area. In very broad terms the lithologies and depositional environments represented by the associations can be summarised as follows. Association A is composed largely of marl-dominated lithologies with minor proportions of sand which were probably deposited around or slightly above normal wave base. Association B is composed of hardgrounds and firmgrounds and associated faunas which are interpreted as representing periods of depositional hiatus during which substrates hardened to a greater or lesser degree and allowed the development of benthic communities dominated by epifauna. Association C is composed largely of calcirudites which are interpreted as representing a series of shallow marine shoals, shell sheets, sandwaves and channels formed in conditions influenced by both waves and tides. Association D is composed of mixed sand and marl lithologies with rare developments of faunas and is thought to have been deposited in very shallow, possibly somewhat restricted, marine conditions which may rarely have been emergent.

Gross lithology and thickness in selected sections are shown in fig. 3 and facies association distribution in fig. 57.

At Herbury no complete section is exposed and the log is a composite derived from the sections along the Fleet shore. Thicknesses in this area are unreliable as the shore sections are crossed by numerous small faults not traceable inland (cf. House, 1961). The sequence of facies associations is certainly correct though, and closely resembles that in the other sections along the Dorset coast. The main difference from the other sections on the Dorset coast is that a second development of Assn. B. (the Digona Bed) developed on a hardground on top of the calcirudites.

Thickness estimates, e.g. Arkell (1947), suggest that the succession is somewhat thicker at Herbury than at Watton Cliff ; approximately 31m as opposed to 28m, but this is certainly not as great as the estimated thick-

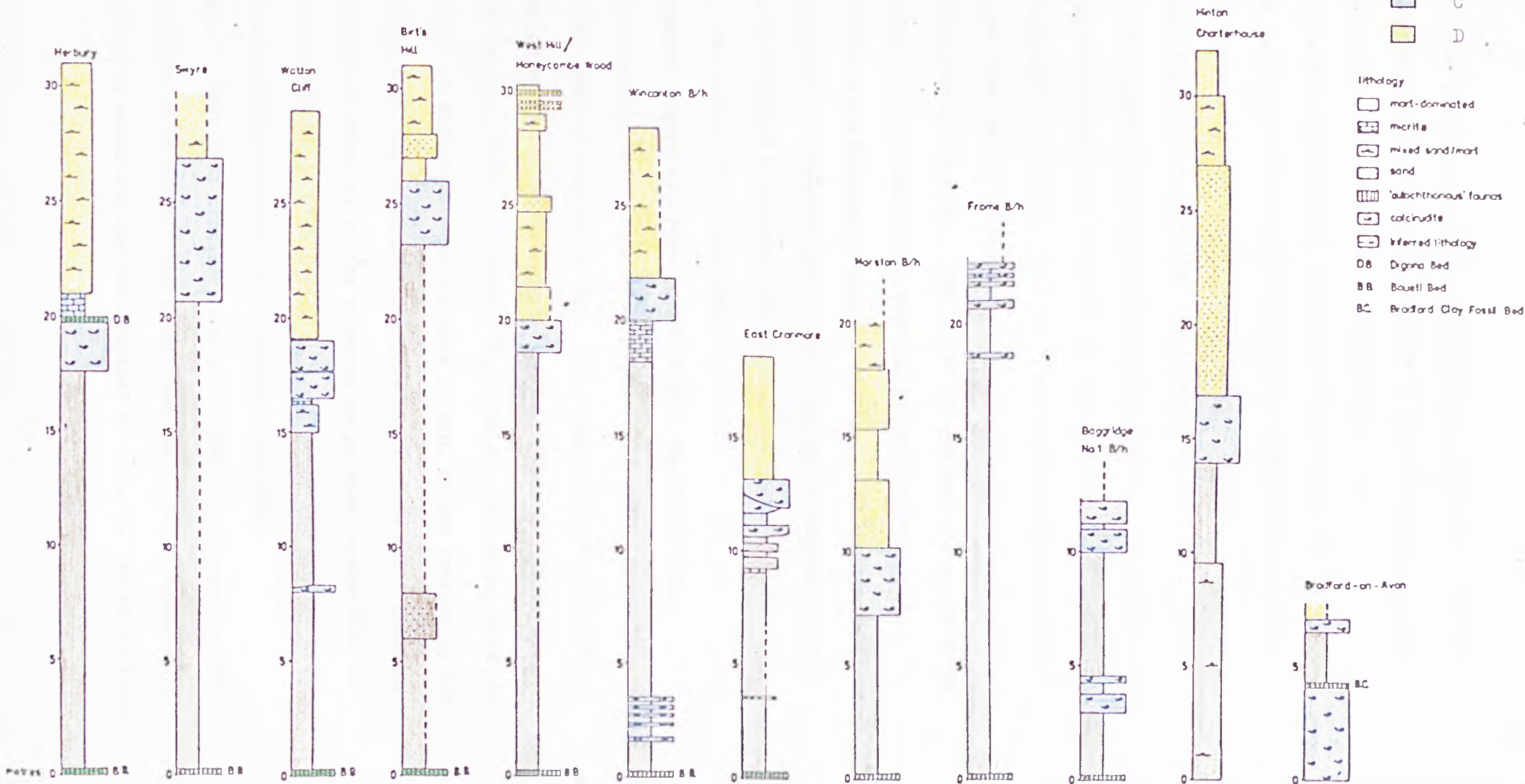
Figure 57. Distribution of facies associations in selected sections in the study area.

Facies Assn.

- A
- B
- C
- D

Lithology

- marl-dominated
- micrite
- mixed sand/marl
- sand
- 'autochthonous' faunas
- calcinudite
- inferred lithology
- DB Dignia Bed
- BB Bouett Bed
- BC Bradford Clay Fossil Bed



nesses in the uncored boreholes to the east of Langton Herring. It is my opinion that thicknesses in this area, on land, if not offshore, may have been distorted by a zone of reverse faulting (see p.4).

Moving inland, the succession at Meerhay is BACD though the development of Assn. D. is thinner than that in the coastal exposures. Further inland the same sequence is present at Birt's Hill, Halstock.

At West Hill, Sherborne a composite log is shown in Fig. 54 . It is compiled from the exposed section, which is all in Assn. D, and data from the adjacent Thornford pipe - trench. At this locality there is only a very thin development of Assn. C. This is a very local change in thickness; up to 5m of calcirudite is present at Longburton less than 2km away. The thickness estimated by Woodward (1894 p.347) is probably exaggerated by small normal faults such as that in the exposed section at West Hill.

Between Sherborne and Wincanton there is little visible change in the succession as exposure is extremely poor. The thickest development of the calcirudites is at Charlton Horethorne (ST 670242) and localities at Henstridge show that Assn. D overlies Assn. C.

In the Wincanton bypass cuttings around Holton the Facies Assn. sequence BACD was observed but in the Wincanton borehole thin calcirudite beds occur near the base of the succession. The sequence in this borehole is open to question as little lithological detail is given on the borehole log (Edwards and Pringle, 1926, pp.183-8). These thin calcirudites also occur at Redlynch, where the visible facies sequence is BCD, though further up the Forest Marble scarp some 50m north of the trackside exposure small quarries suggest the presence of Assn. C, so the sequence is probably comparable to that in the Wincanton borehole with a thin development of calcirudite within marl dominated sediments below the main calcirudite horizon.

The sequence at Seat Hill near Batcombe (ST 707394) is apparently BACD. In the stream section at ST 707394 the Boueti Bed could not be found but a thin sequence of marls underlies the calcirudites of Assn. C. As at Redlynch

the Boueti Bed is very close to the scarp of the calcirudites, suggesting, in the most general terms, that Assn. B thickens to the south.

West of Wanstrow, at East Cranmore the sequence of Facies Assns. is BACD. Assn. C is represented almost entirely by channels.

Borehole evidence at Marston and Frome shows that above the provisional base of the Forest Marble (excluding Upper Rags) the sequence is BACD and BAC respectively. Brash from Assn. D may be found at the top of the scarp at Gibbet Hill, Frome suggesting that the complete sequence is again BACD. In both these boreholes minor developments of Assn. B occur in Assn. A.

The section in the Hinton Charterhouse borehole (Penn and Wyatt, 1979 p. 47) probably shows the Facies Assn. sequence ACD but this is difficult to confirm from the figured log. The stream section at ST 786573 between Hinton Charterhouse and Norton St. Philip confirms the upper part of this succession as CD.

At Baggridge Hill there is considerable facies variations over a very short distance in the three borehole logs (fig. 58).

The succession in the study area is therefore fairly constant at the facies association level. The main departures from the typical sequence BACD occur with the development of the lower calcirudite beds around Redlynch and Wincanton and to the north of this area where the Forest Marble sensu Green and Donovan (1969) overlies the Upper Rags.

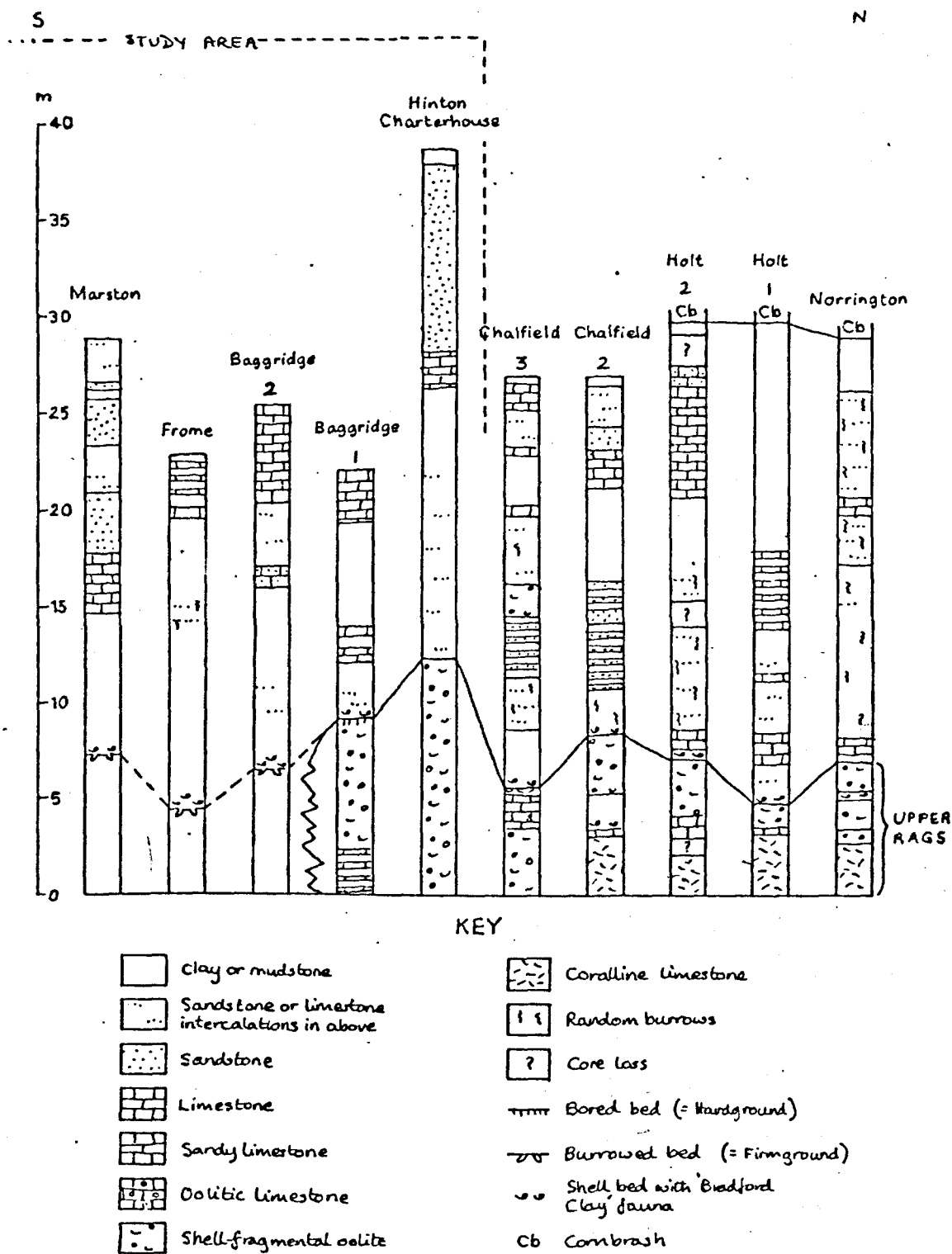


Figure 58. Comparative vertical sections through the Forest Marble in selected boreholes in the Bath - Frome area. Adapted from Penn and Wyatt (1979) fig. 13.

Interpretation of the succession.

In the area south of Wincanton, the succession is remarkably constant. At the base is the Boueti Bed which rests on a patchily developed hardground or firmground and is in turn overlain by up to 23m of marl-dominated sediments which only contain macrofaunas where hardgrounds or firmgrounds are developed.

The fauna of the Boueti Bed shows a certain amount of community succession but is essentially an epifaunal benthic marine community. It contains many groups characteristic of open marine faunas, but cephalopods are very rare. Nine brachiopod, three echinoderm, eleven bryozoan, two cephalopod genera and one coral genus are present. All these groups are considered to be broadly stenotopic (e.g. Heckel, 1972), though it has recently been pointed out that Recent epifaunal benthic communities composed largely of bivalves, echinoderms, brachiopods, corals and serpulids, with subsidiary elements including bryozoans and sponges, occur in conditions of less than normal marine salinity in the Strait of Georgia, between Vancouver Island the mainland of Canada (G. Farrow - lecture to Geological Society of Edinburgh, February, 1981). Thus there is at least a possibility that these faunas may have developed in less than fully marine salinities.

Whether similar conditions of salinity continued during the deposition of the overlying marls is uncertain but conditions appear to have been similar, at least when depositional hiatuses occurred and faunas developed.

The marls of facies association A probably represent a shallowing upwards sequence in both well exposed sections; at Watton Cliff and East Cranmore.

Above the marls are shoals, sandwaves, channels and shell sheets of coarse calcirudite which suggest the presence of both tidal currents and waves and show evidence of the operation of storm processes. The presence of channels between and within shoals suggests that they may have formed at least a partial barrier to the exchange of water between the adjacent

environments. Near the shoals thin micrites with a mixed infaunal and epifaunal community developed. Only one shoal in the area south of Wincanton has been colonised. This has a hardground developed on its top; the Digona Bed hardground, which is restricted in its development to the area around Langton Herring. This fauna was probably the most stenotopic in the whole Formation. Considering the small area in which it is developed it has a relatively high density of cephalopods and also the greatest bryozoan diversity of all the faunas in the study area. In these respects the fauna is the most similar to those of the same age in Normandy. The lithology of the Digona Bed clearly indicates high energy conditions.

Sequentially above the main calcirudite bodies, facies association D is always developed. This contains evidence of deposition in extremely shallow water. Oyster reefs are present and occasionally evidence of emergence may be found; mudcracks and probably emergent bars are present. Finely divided plant debris is abundant. Trace fossils associated with very shallow water, such as oblique Rhizocorallium, are found.

The macrofaunas, whilst containing no clearly fresh or brackish water taxa, are composed dominantly of genera considered to be eurytopic. No cephalopods or corals and only two echinoids (both vagile), one brachiopod and two bryozoans are known from autochthonous faunas.

Thus the sequence in the area south of Wincanton can be accounted for by a simple regressive sequence marking a change from 'open marine' muddy shelf conditions around wave base to very shallow, occasionally emergent, somewhat restricted marine conditions.

The simplest explanation of the sequence is that it is diachronous and represents a series of channels, shoals, sand waves and sand sheets separating an open muddy shelf from a somewhat restricted shallower water environment.

From Wincanton northwards, the broad overall shallowing upwards sequence is still apparent, but is not so clearly developed. Towards the base of the Formation the more 'open marine' faunas, represented by the Boueti Bed,

Bradford Clay Fossil Bed and isolated lenses of bradfordian faunas, do not occur sequentially above the main calcirudite bodies. They may occur attached to the tops of calcirudite bodies, as at Bradford-on-Avon, but never within the sediments of facies association D. In all sections examined the top of the Forest Marble is composed of sediments of facies association D. Oyster reefs are found in these sediments, e.g. at Witham Friary.

Some complexities occur in the sequence in this area however. Calcirudites may be present very near the base of the Formation, e.g. around Redlynch and Wincanton, and thick sand bodies are developed towards the centre or top of the Formation in the area around Hinton Charterhouse and Farleigh Hungerford. Thus both carbonate and clastic sand bodies are present and these do not so clearly delineate separate environments at the base and top of the succession. This is apparent at East Cranmore Railway Cutting, where the differences in the sediments above and below the calcirudites are less marked than in south Dorset, at Watton Cliff for example.

The large thick sand bodies found in the vicinity of Farleigh Hungerford, Hinton Charterhouse, Beckington and Rudge are the Hinton Sands of previous authors. They are elongate and lensoid in geometry. Internally they contain small channels. The origin of these sand bodies is unknown, though they probably represent shallow near-shore shoals. The evidence for this is based, to some extent at least, on the circular argument that they occur in very shallow water facies. It is notable that the main occurrence of these thicker sand bodies is close to the southern limit of the Great Oolite limestones and the Mendip Axis of Arkell (1933) and others.

There appear to be some lines of evidence to support an overall northward shallowing of the succession. Firstly the sequence in Dorset is less complex than that in the north of the study area. Secondly it has towards its base a thick and almost uninterrupted broadly coarsening upwards sequence which is not so clearly developed north of Wincanton. Thirdly the Forest Marble as a whole thins considerably between Hinton Charterhouse and the area around

Melksham and Norrington; from some 28m to around 22m (Penn and Wyatt, 1979 p. 57). Lastly this northerly or northeasterly thinning is reflected in the Bathonian isopach map (fig. 2), which suggests a progressive thickening of the Bathonian towards south Dorset and away from the Anglo-Belgian landmass.

Superimposed on this assumed overall shallowing of the depositional environment there may have been a break of slope around the southern slopes of the Mendips, north of which there is a subtle change in the lithologies and sequences indicating perhaps a more consistently shallow, but still shallowing upwards, sequence of environments.

It is proposed that the regressive nature of the Forest Marble in the study area and the southwestward deepening of the Bathonian basin indicate a southwestward progradation of the shoreline into deeper waters, particularly south of the Mendips. The environmental picture in the study area is summarised in fig. 59.

Regional Considerations

Very little published information is available on the depositional environment of the Formation between Burford and Bath. However, there are indications that in places the top of the Formation was emergent. M. Ware and T. Windle have examined a section immediately beneath the Cornbrash at Tarlton, Glos. in which freshwater ostracods are present. These are well preserved, reasonably abundant and both adults and juveniles are present, suggesting that the faunas are autochthonous. Brackish and marine faunas are also present at slightly different levels. A microflora including Lycopod megaspores is present. As no extant Lycopods are known from salt marsh or marine habitats, the proximity of land and fresh water is strongly suggested (M. Ware, pers. comm. 1980).

Secondly the footprints described by George Poulett Scrope (1831) come from sands of facies association D in Wiltshire and strongly suggest emergence.

In the areas between Bath and Burford it is clear that bradfordian faunas (of probable 'open marine' origin) occur fairly near the base of the Formation, e.g. Woodward (1894), Cave (1978), Barker (1976) and these, even if they are only patchily distributed, tend to suggest an overall regressive sequence similar to that postulated in the study area.

This is not clearly the case in the area to the northeast around Oxford. Here bradfordian faunas are distributed throughout the Formation. For example the famous Islip fauna occurs less than 3m below the Cornbrash (T. Palmer, pers. comm. 1980). At Shipton-on-Cherwell there is little sedimentological evidence to support a clearly regressive sequence. At Croughton Quarry, Oxon. the Forest Marble is of less marine aspect than at Shipton-on-Cherwell. It overlies an emergent horizon at the top of the Bladon member of the White Limestone, which is penetrated by rootlets. It is composed largely of black, highly carbonaceous mud with patchily developed faunas which include Macunopsis sp., Bakevillia waltoni, Protocardia sp., Eomiodon fimbriata, Corbula hulliana and Corbula sp. Dinosaur remains and very large quantities of plant remains are also present. These sediments probably represent swampy conditions and pass northeastwards into the Blisworth Clay.

In the Formation as a whole, then small areas of emergence were present at various times in several places throughout the outcrop. Some of these must have been of sufficient size to allow the development of land plants, freshwater ostracods, dinosaurs and mammals. In the Oxfordshire area, where the Forest Marble is very thin, these do not appear to occur selectively at the top of the succession, as is the case to the southwest.

This is compatible with a model in which gradual deepening occurred off the Anglo-Belgian Landmass to the vicinity of the Mendips. A slight break of slope may have existed around the Mendips. South of this break of slope,

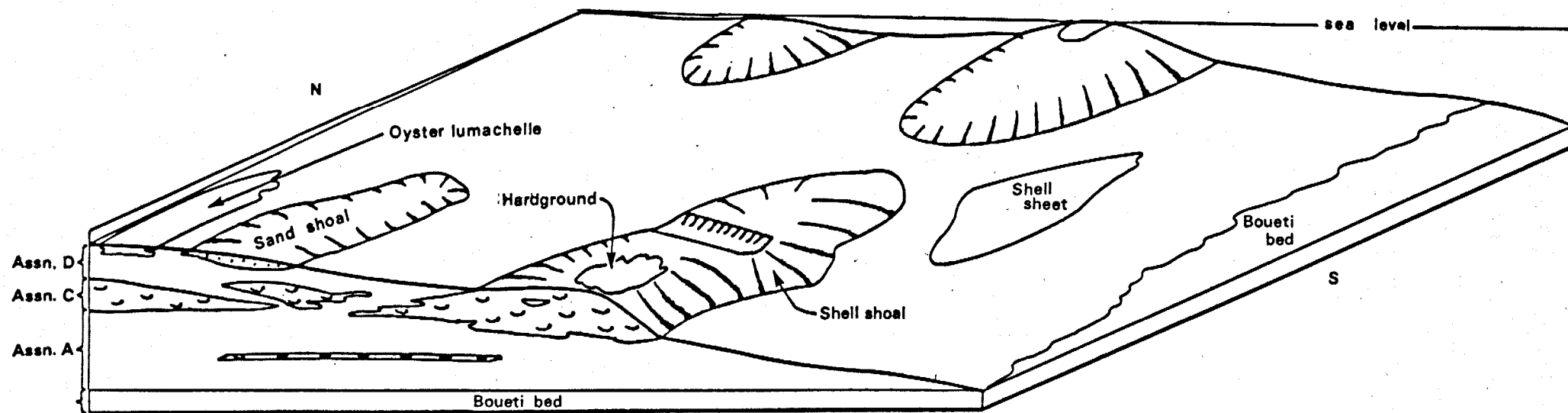


Figure 59. Diagram illustrating proposed distribution of environments in the study area during Forest Marble times.

deeper water at the start of Forest Marble deposition is reflected in the thicker succession and the greater contrast between the sediments and faunas at the top and base of the Formation. Offshore, borehole records indicate that the sequence may thicken considerably towards a depocentre in the Channel Basin.

APPENDIX 1. Methods and results of analysis of clay mineralogy and organic carbon content of sediments.

a) Clay mineral analysis

Method. The samples were dispersed in water and sedimented overnight. The clay fraction was siphoned off, plated and analysed in an X-ray diffractometer. Presence / absence data for micas, chlorite, illite, kaolinite and montmorillonite are given in the table below. Samples were collected at metre intervals from the base of the Boueti bed at Watton Cliff to the highest accessible point of the cliff section.

Sample number	Micas	Chlorite	Illite	Kaolinite	Montmorillonite
1(base Boueti bed)	X	-	X	X	-
2	X	-	X	X	-
3	X	-	X	X	-
4	X	-	X	X	-
5	X	-	X	X	-
6	X	-	X	X	-
7	X	X	X	X	-
8	X	-	X	X	-
9	X	-	X	X	-
10	X	-	X	X	-
11	X	-	X	X	-
12	tr	-	tr	tr	-
13	X	-	X	X	-
14	X	-	X	X	-
15	tr	-	tr	tr	-
16	tr	-	tr	-	-
17	tr	-	tr	-	-
18*					
19	tr	-	tr	-	-
20	X	-	X	X	-
21	tr	-	X	X	-
22	-	-	tr	-	-

X present

- absent

tr trace

* No sample as bioclastic limestones outcrop at this height.

b) Organic carbon content

Method. The carbonate carbon was dissolved in 2% HCl and the samples neutralised with ammonia. They were then analysed for carbon on a Perkin Elmer Elemental Analyser.

Eight samples were analysed, all from Watton Cliff. Five of these were from the marls of facies 1, two from the silty marls of facies 2 and one from the marls interbedded with sand lenses of facies 15. Results are presented in tabular form below:

Sample number	Facies	% organic carbon
1	1	2.21
2	1	2.31
3	1	2.53
4	1	3.32
5	1	4.22
6	2	0.90
7	2	4.40
8	15	1.81

APPENDIX 2.. Details of localities and sections in Facies Association B, (Hardgrounds and Firmgrounds Facies Association) not included in Chapter 3¹

A. BOUETI BED

1) Herbury Promontory. The Boueti Bed outcrops on the southwest tip of the promontory and is cut off by a fault immediately to the east. It overlies thinly interbedded sand and marl lenses heavily bioturbated by oblique Rhizocorallium. The bed itself is composed of a grain supported coquina with a marl matrix up to 40cm. thick. The upper 15cm. is dominated by Catinula ancliffensis. The faunal list below is compiled from Richardson (1909), Engleheart (c. 1925) and Arkell (1947) with minor additions from personal collections.

Goniorhynchia boueti

Pholadomya sp.

Avonothyris langtonensis

Catinula ancliffensis

Dictyothyris coarctata

Praeexogyra hebridica

Digonella sp.

? Kutchithyris sp.

Apiocrinus parkinsoni

Acrosalenia spinosa

Pleurotomaria burtonensis

Delecticeras cf. ptychoporum

Turbo burtonensis

Belemnite fragment

Patella rugosa

Dorsoserpula sp. 2

Gervillella sp.

Tetraserpula sp.

Arcomytilus asper

Cycloserpula sp.

Vaugonia moretoni

Sarcinella socialis

Camptonectes annulatus

Berenicea parvitubulata

Placunopsis socialis

Radulopecten vagans

B. sauvagei

R. hemicostata

Stomatopora waltoni

¹ All faunal lists are compiled from personal collections unless otherwise stated.

Neuropora spinosa

Peronella pistilliformis

Webbina sp.

Proboscina sp.

2) Cliff End, Burton Bradstock (SY 496886). The Boueti Bed is exposed at the top of gullies in the recently slipped cliff section.

The fauna is:

Goniorhynchia boueti

Avonothyris langtonensis

Dictyothyris coarctata

Digonella bradfordensis

Acromytilus asper

^e
Girvillella acuta

Radulopecten vagans

Radulopecten hemicostata

Catinula ancliffensis

Lopha sp.

Nicaniella (Trautscholdia) cordata

? Modiolus imbricatus

Dorsoserpula sp.

Peronella sp.

Apiocrinus sp.

Although many Boueti Bed fossils may be collected on Burton Common, the bed does not outcrop at this locality.

3) Swyre. The Boueti Bed is exposed immediately below the track leading to Swyre quarry (SY 523880). The fauna is:

Goniorhynchia boueti

Avonothyris langtonensis

Digonella bradfordensis

Turbo burtonensis

Arcomytilus asper

Radulopecten vagans

Catinula ancliffensis

Praeexogyra hebridica

Montlivaltia slatteri

Dorsoserpula sp.

Tetraserpula sp.

4) East Bexington, 850m. E.S.E. of East Bexington Dairy House.

Here the bed overlies plane bedded burrowed coarse sand. The faunal list below is compiled from Wilson et al. (1958) and personal collections.

Goniorhynchia boueti

Avonothyris langtonensis

Kutchirhynchia communalis

Kutchirhynchia sp.

Kutchithyris sp.

Digonella sp.

Arcomytilus asper.

Catinula ancliffensis .

Praeexogyra hebridica

Dorsoserpula sp.

5) Sutton Bingham. A small exposure is present at the entrance to Bingham Bowers Farm (ST 543095) on the west side of the road. Bored pebbles are present at this locality. The fauna collected was:

Goniorhynchia boueti

Avonothyris langtonensis

Catinula ancliffensis

The trace fossil Trypanites is also present.

6) Charleton Horethorne. Loose specimens of the species listed below are recorded from the stream section at ST 677293.

Goniorhynchia boueti

Avonothyris langtonensis

Digonella digona

There is a notable lack of Catinula ancliffensis at this locality.

7) Jack White's Gibbet. The fauna below was recorded from a road cutting on the north side of the A371 at the junction of the west side of the Bratton Seymour road at ST 677293.

Goniorhynchia boueti

Digonella sp.

Avonothyris langtonensis

Radulopecten vagans

Catinula ancliffensis

Dorsoserpula sp.

8) Sheephouse Farm, Bruton (ST 700365). A hardground is present beneath the bed in the field immediately southwest of the farm building. The fauna is:

Goniorhynchia boueti

Avonothyris langtonensis

Radulopecten sp.

Catinula ancliffensis

Lithophaga sp.

9) Seat Hill, Batcombe. A temporary exposure in a drainage trench at ST 707394 in a field on the corner between the A359 and the Batcombe road yield the fauna below. This was the most northerly exposure of the Boueti Bed visited by the author.

Goniorhynchia boueti

Avonothyris langtonensis

Eudesia cardium

Rhactorhynchia sp.

Rhynchonelloidella sp.

Camptonectes ?retiferus

Radulopecten vagans

Catinula ancliffensis

Dorsoserpula sp.

'Cidaris' bradfordensis

B. DIGONA BED

Apart from these localities mentioned in Chapter 3, the only locality at which collections could be made is at Abbotsbury Hill (SY 564855). Here collections were made from field brash. No hardground was recorded and the recorded specimens are all blocks

of coarse sparry calcirudite. Following Sylvester-Bradley (1957) I consider this horizon to be the Digona Bed though it has been identified as the Boueti Bed (Wilson et al., 1959). The fauna recorded is:

Avonothyris sp.

Eudesia cardium

Epithyris sp.

Modiolus imbricatus

Oxytoma costatum

Camptonectes annulatus

Camptonectes rigidus

Camptonectes (Camptochlamys) retiferus

Chlamys (Radulopecten) vagans

Plicatula fistulosa

Pseudolimea duplicata

Praeexogyra hebridica

Exogyra crassa

Apiocrinus parkinsoni

Other Digona Bed localities have been recorded by Sylvester-Bradley (1957) and House (1961). These are: Stony Heaps Plantation (SY 619821), Rodden Hive (SY 608824), South Sleight Knap (SY 600827) and West Fleet (SY 618813).

Appendix 3. Experiment to simulate production of imbrication in calcirudite.

In an experiment to determine the effects of unidirectional currents on whole shells, single whole Mytilus edulis valves were distributed in a layer 10 to 15cm. thick on the base of a flume 80cm. wide. Those valves beneath junctions on an 8cm. sampling grid were numbered 1 to 90 and their orientation of both the long axis and the commissure plane of each valve was measured. The orientation of the long axes are shown in figures 19 and 20.

The flume was run under the following conditions:

Slope of water: $1:8.49 \times 10^{-4}$

Depth of water: 8 - 10cm.

Discharge: 53 litres/sec.

Surface velocity: approx. 50cm./sec.

A preferred orientation of the long axes of the valves parallel to the current direction was noted after two hours, but a number of other stable orientations were also observed. Principally valves with the commissure plane vertical and the convex side upstream stacked against each other in a similar manner to a pile of saucers and forming very stable patches of sediment. The contouring of stereograms before and after the run shows that the current induced a tendency for the commissure planes to lie almost flat with the umbo pointing slightly downward and upstream, see stereoplots (figs. 19, 20). The majority of shells were convex up. During the run, many shells appeared to reorientate into an imbricated position by shuffling movements at the same spot rather than by significant downstream movement, though no measure of downstream movement of the shells was made.

Figure 19a. Stereoplots of density of poles to the commissure planes of whole Mytilus edulis valves in flume before run. Current from south to north.

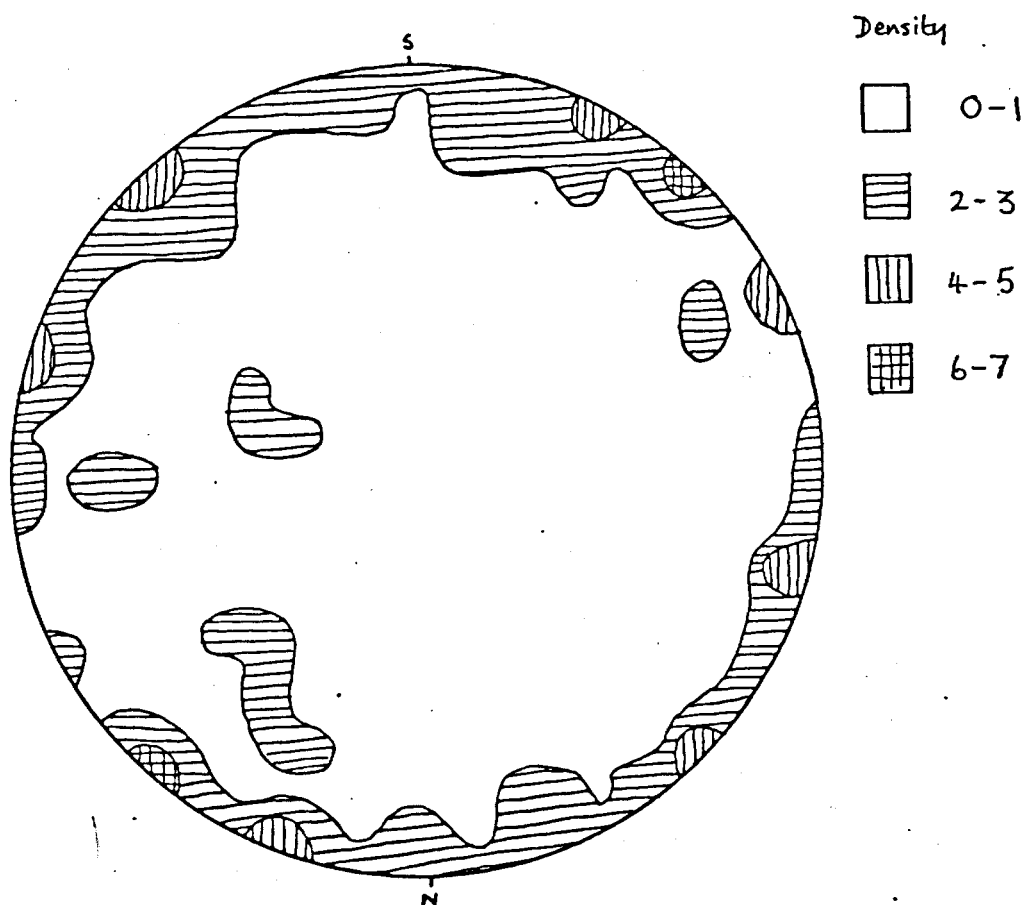


Figure 19b. Orientation of long axes of whole M. edulis valves in flume before run. $n=90$

Azimuths measured
towards umbo.

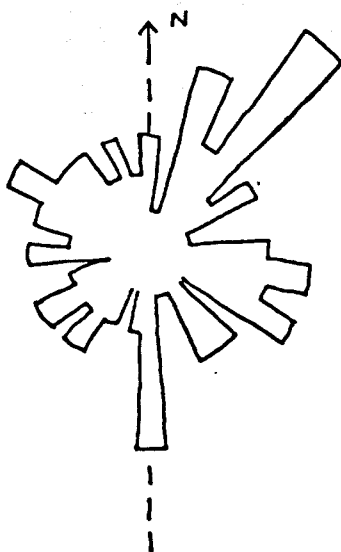


Figure 20a. Stereoplots of density of poles to the commissure planes of whole Mytilus edulis valves in flume after run. Current from south to north.

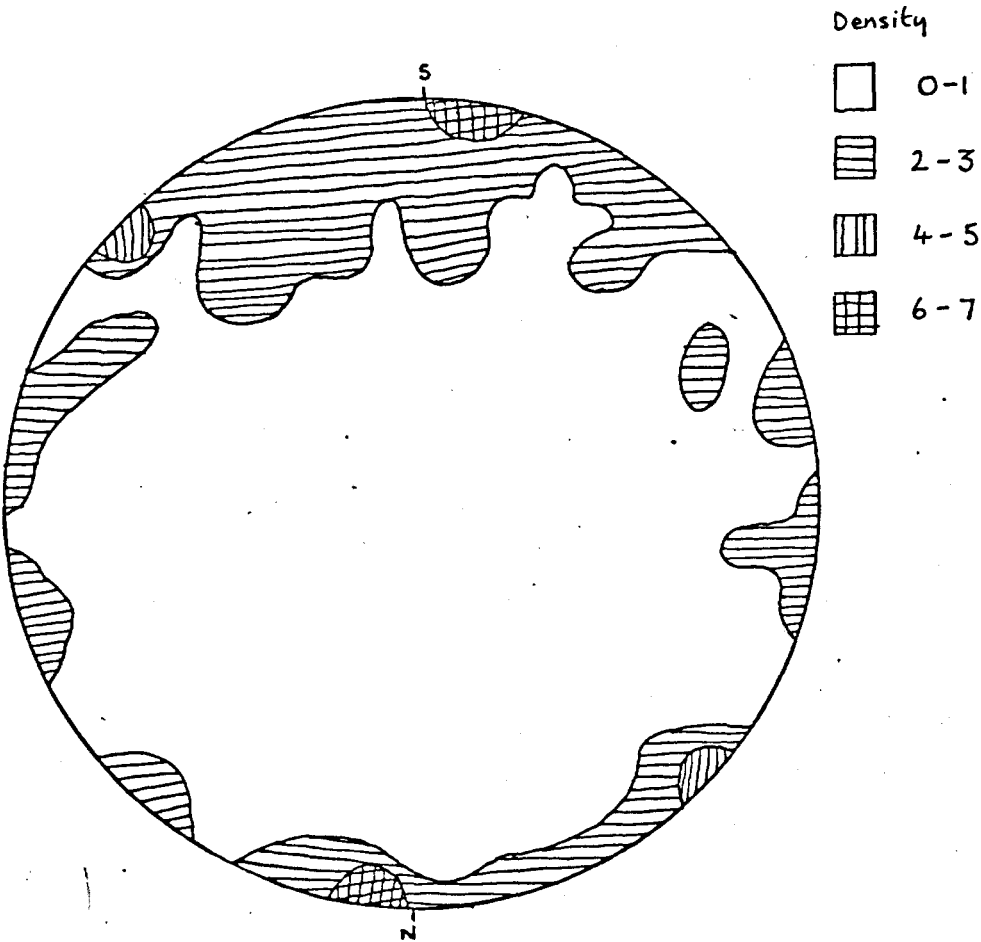
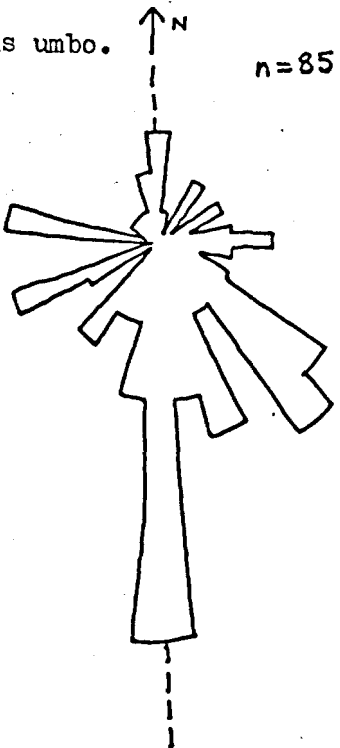


Figure 20b. Orientation of whole M. edulis valves in flume after run. Azimuths measured towards umbo.



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